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Analysis of SSN 688 class submarine maintenance delays

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS OF SSN 688 CLASS SUBMARINE MAINTENANCE DELAYS

by

R. Leon Lary IV

June 2017

Thesis Advisor:	Nick Dew
Co-Advisor:	Keebom Kang

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In this thesis, data collected from Pearl Harbor Naval Shipyard (PHNSY) is analyzed to investigate possible factors impacting the ability of maintenance activities to complete SSN 688-class submarine maintenance availabilities as scheduled. The analysis illustrates a systematic underestimation of availability duration due to the use of outdated historically based estimates following a significant shift in maintenance strategy in 2012. Additionally, the analysis shows a significant increasing trend in the average number of man-days required to complete a job. This thesis provides a narrowed focus for future studies attempting to determine the cause of this trend. Finally, this thesis proposes a solution to the systematic underestimation of availability durations by illustrating the inherent error in the current equation and providing a notional equation to remove that error.

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ANALYSIS OF SSN 688 CLASS SUBMARINE MAINTENANCE DELAYS

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Submitted in partial fulfillment of the
requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

Ao	operational availability
AQWP	Actual Quantity of Work Performed
BQWP	Budgeted Quantity of Work Performed
CMAV	Continuing Maintenance Availability
COMSUBOAC	Commander Submarine Force U.S. Pacific
CP	Cost Performance ratio (BQWP/AQWP)
CPE	Corporate Planning Estimate
D-Level	depot level maintenance
DMD	Dual Media Discharge
DMP	Depot Modernization Period
DOD	Department of Defense
DSRA	Docking Selected Restricted Availability
EOC	Engineered Operating Cycle
EOH	Engineered Overhaul
Fleet alt	fleet-wide required engineered alterations
FLTCDR	Fleet Commander
FMA	Fleet Maintenance Activity
FRE	Final Review Estimate
FRP	Force Readiness Plan
I-Level	Intermediate Level
IMF	Intermediate Maintenance Facility
JIC	Joint Inflation Calculator
NAVSEA	Naval Sea Systems Command
NCCA	Naval Center for Cost Analysis
OFRP	Optimized Fleet Response Plan
OPCYCLE	Operational Cycle
OPINTERVAL	Operational Interval
OPTEMPO	Operational Tempo
PHNSY	Pearl Harbor Naval Shipyard
PM	Phased Maintenance

PMR	Planned Maintenance Requirement
POM	Pre-Overseas Movement
QAC	Quantity at Completion
SA00	Start Availability Date
SEOC	Submarine Engineered Operating Cycle
SHAPEC	SSN Ship Availability Planning and Engineering Center
SSN	Nuclear-powered Attack Submarine
SUBMEPP	Submarine Maintenance Engineering, Planning and Procurement
SUBPAC	Submarine Force Pacific
SWLIN	Ship Work Line Item Number
TFP	Technical Foundation Paper
URO	Unrestricted Operations

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I. INTRODUCTION

A. PURPOSE

Progressive increases in cost, manpower, and duration requirements for the U.S. Submarine Force are directly affecting its ability to plan and execute the Navy's mission. Commander Submarine Force U.S. Pacific (COMSUBPAC) identified this four-year trend in 2015 following a naval shipyard external performance review (COMSUBPAC, 2015). In response to the trend of elevated attention on shipyard performance and an increasingly constrained fiscal environment, SUBPAC N4 has made yearly visits to the Naval Postgraduate School in order to coordinate directed research in an effort to help investigate the root causes of project growth in Depot and Intermediate level maintenance availabilities.

1. Problem Statement

From FY12 to FY16 only 38.8 percent of all nuclear-powered attack submarine (SSN) Intermediate-level maintenance availabilities at Pearl Harbor Naval Shipyard were completed on time. Naval Sea Systems Command (NAVSEA) has a corporate goal of 100 percent on-time completion.

Maintenance overruns create the following problems:

1. Lost operational availability (Ao), and, therefore, a lack of available submarines to execute required missions. This may present a critical risk factor for the nation. This maintenance availability overrun has resulted in an average loss of 450 operational days per year (COMSUBPAC, 2015). The accumulated total late days shows the effective lost Ao due to lateness. Projections for PHNSY & IMF for FY17 are shown in Figure 1.

2. Longer time in a maintenance availability period, which results in extra costs that stress the Navy's budget by creating un-programmed funding demands.

3. Increased uncertainty as to future maintenance planning.

In order to recalibrate NAVSEA's models it is essential to understand what factors are driving maintenance delays today.

The effect of late days on the overall loss to Ao is clear to be seen in Figure 1; the late day codes, however, fail to provide any insight into the root causes of the delays.

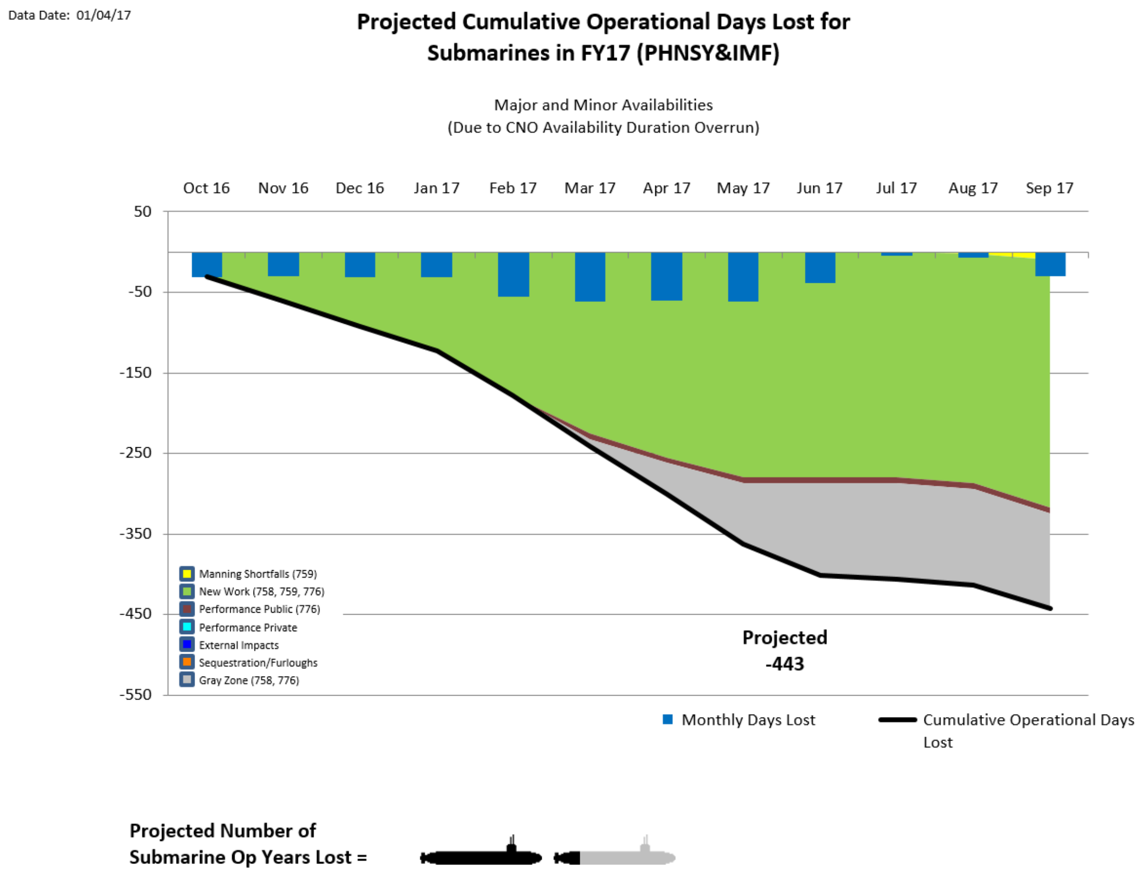


Figure 1. Projected Cumulative Operational Days Lost for Submarines in FY17 at PHNSY & IMF. Adapted from SUBPAC N4 (2017).

2. Research Questions

The primary research questions addressed:

1. Is the negative trend in submarine maintenance availability execution primarily a problem of cost, schedule, or performance?
2. What are the key factors influencing the negative trend(s) identified above.
3. How can the Navy focus funding in order to best position the Pacific submarine fleet going forward?

B. BENEFIT OF STUDY

In September 2009, Fleet Commanders Admiral Harvey and Admiral Willard directed a comprehensive assessment of Surface Force Readiness, which resulted in identifying "improvements necessary to sustain near-term operational commitments while achieving ship wholeness and expected service life" (COMSUBPAC, 2015). In conjunction with follow-on research, this thesis attempts to recommend opportunities or strategies that will optimize the Navy's use of its allocated resource pool. Two critical factors increasing the importance of this effort are the impending attack submarine inventory shortfall and the resource constrained budget environment.

1. Attack Submarine Inventory Shortfall

Optimizing Ao is of critical importance to the submarine fleet as it approaches a shortfall of operational submarines, depicted in red in Figure 2. Based on current estimates, the Navy is set to dip below its official stated requirement of 48 submarines starting in FY25.

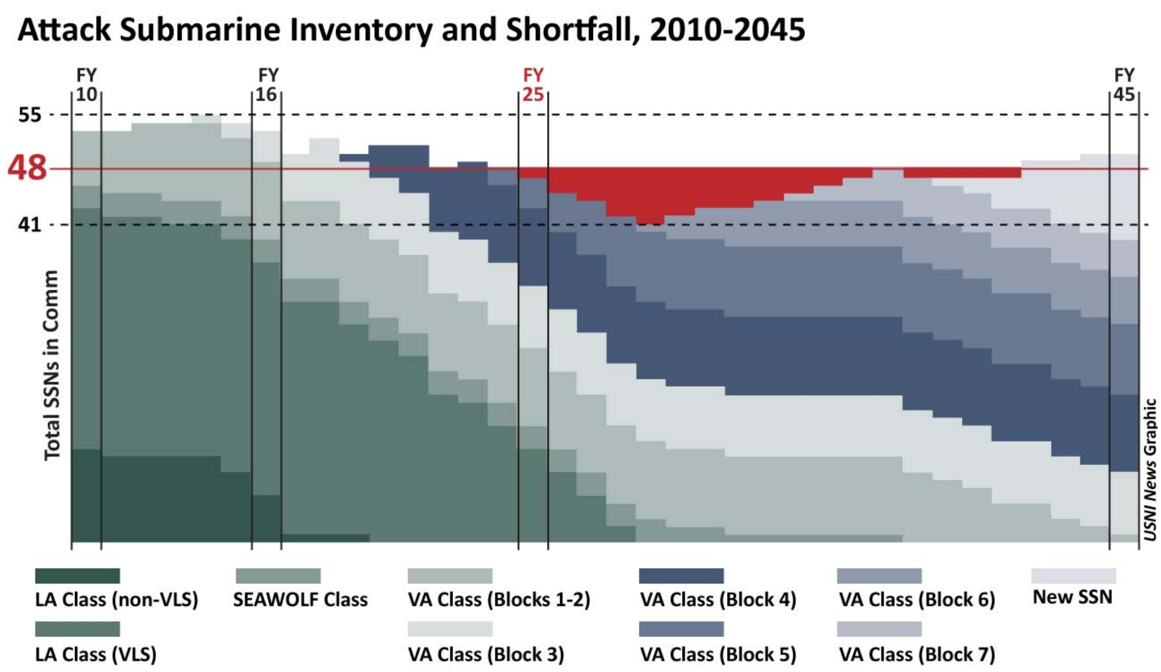


Figure 2. Attack Submarine Inventory and Shortfall, 2010–2045. Source: Eckstein (2016).

2. Resource-Constrained Environment

As the United States Department of Defense (DOD) continues to operate in a resource-constrained environment, the efficient use of the Navy's resources is critical to limiting underperformance. Due to most organizations operating with constrained resources, each must accomplish as much as possible in order to underperform as an organization as little as possible. Defense discretionary spending has been and will likely continue to be squeezed due to the increasing burden of mandatory entitlements and debt interest on the federal budget. Therefore, the struggle for defense funding presents a critical risk factor for the efficient use of existing funding. The lack of real growth in Defense spending over the last 50 years is shown in Figure 3.

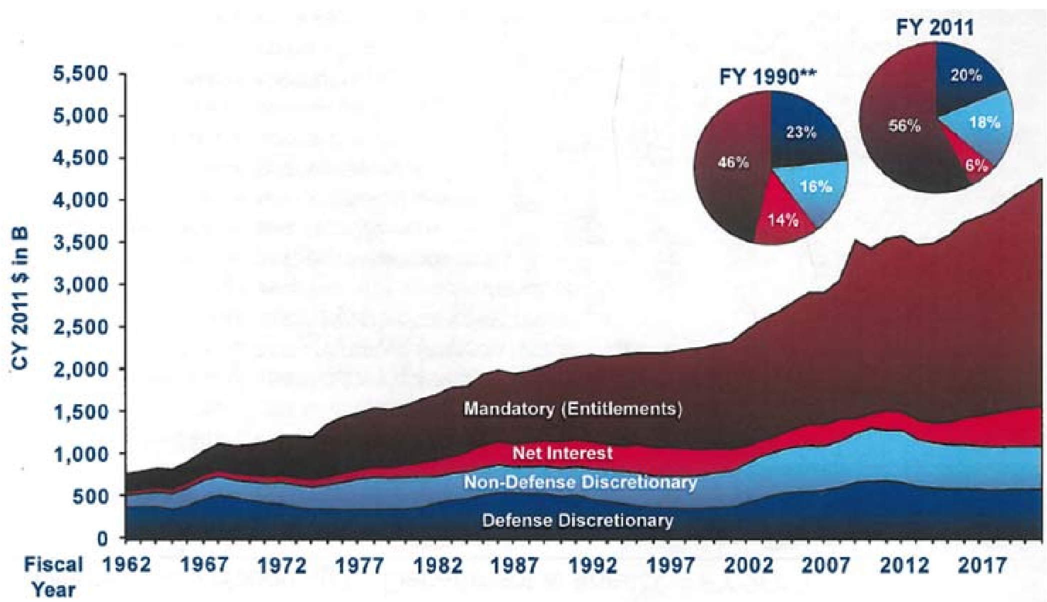


Figure 3. Federal Spending in CY2011 $B. Source: Kim (2016)

Over the period 1993–2015, the U.S. Navy has reduced its fleet from 454 to 272 ships while maintaining a similar level of globally deployed ships. This has resulted in an increased operational tempo (OPTEMPO) evidenced by the growth in average deployment length from 167 days to 272 days shown in Figure 4 (Luther, 2016).

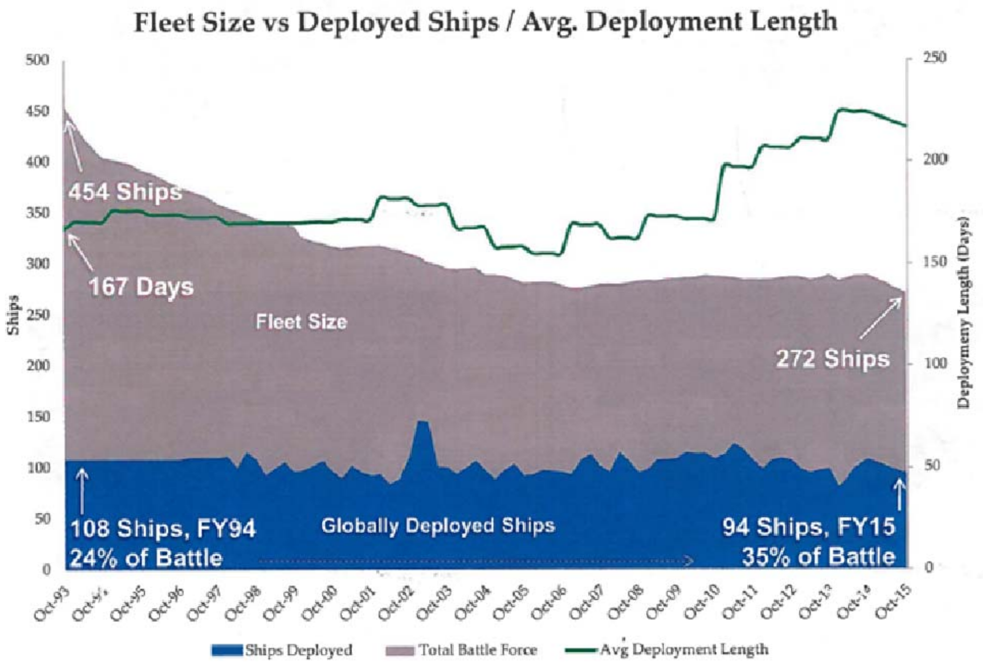


Figure 4. Deployment Length and Naval Fleet Size. Source: Luther (2016).

In an environment where funding is tight and asset utilization (deployment length) is at all-time highs, on-budget and on-time maintenance of those investments becomes critical to having the available capabilities needed to execute the Navy's missions. Unfortunately, Navy-wide ship depot maintenance has over-executed its budget by an average of $770 million per year from FY10 to FY16, as seen in Figure 5.

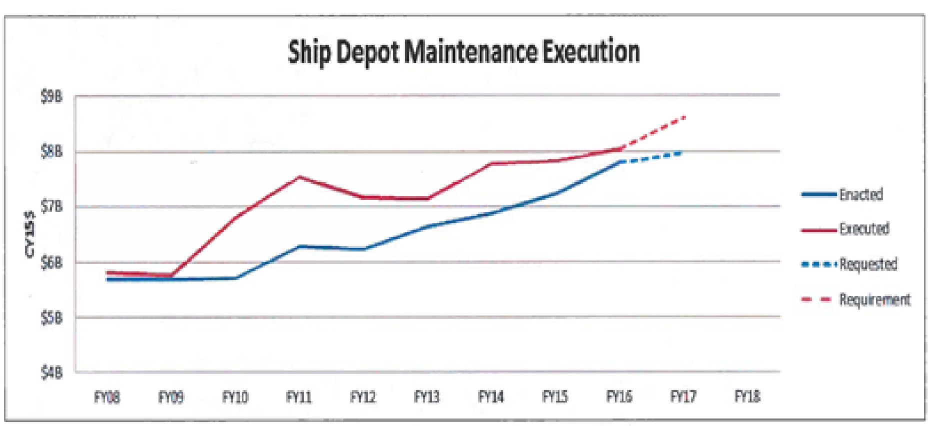


Figure 5. Navy-Wide Ship Depot Maintenance Over-Execution FY08–FY17. Source: Luther (2016).

C. SCOPE OF THESIS

Studies have been conducted within the last 20 years on depot level availabilities analyzing historical data from several shipyards across several hull types (e.g., Caprio & Leszczynski, 2012; Kalowsky, n.d.). While some studies have identified marginal correlations, most have been unsuccessful in determining the root cause of maintenance over-execution due to the unique nature of each type of availability, hull, and shipyard. An analysis covering all hull types and shipyards prevents an "apples to apples" comparison. A better analytical approach is to limit the scope of the analysis by using only the same hull type, shipyard, and maintenance availability type. For that reason, this analysis is limited to historical data collected from maintenance availabilities conducted exclusively at Pearl Harbor Naval Shipyard (PHNSY) and only on Los Angeles (SSN 688)-class submarines. Being the higher quantity and older generation submarine hull type, the Los Angeles class submarine also presents the best target for providing as much historical data as possible under a limited scope. Data is more readily available at PHNSY versus other shipyards due to the primary sponsor, SUBPAC N4, being located at PHNSY. Finally, each analysis only looks at one type of availability at a time in order to eliminate the effects of differing scopes of work conducted under each availability type.

II. BACKGROUND

A. SUBMARINE MAINTENANCE PRACTICES

Submarine Maintenance is guided by the Submarine Engineered Operating Cycle program (SEOC). This CNO-approved maintenance program contains both a Class Maintenance Plan (CMP) and a maintenance strategy (OPNAV N9, 2013). Each CMP contains all of the organizational, intermediate, and depot level maintenance requirements and periodicities for that class of submarine based on the designed service life of its systems and components. The two submarine maintenance strategies currently in use are the phased maintenance (PM) strategy and the engineered operating cycle (EOC). The Ohio- and Seawolf-class submarines use a PM strategy, which consists of short, frequent availabilities in lieu of large overhauls. The Los Angeles- and Virginia-class submarines use an EOC strategy, which uses a “structured engineered approach” of specified D-Level, and I-Level availabilities (OPNAV N9, 2013).

1. Levels of Maintenance

Submarine maintenance is conducted at three separate levels based on the resources and capabilities required to do the maintenance: Organizational, Intermediate, and Depot Levels (OPNAV N431, 2010).

a. Organizational-Level

The lowest level of maintenance is called Organizational-Level (O-Level) maintenance, which consists of maintenance within the capability of the ship’s force. The Submarine’s Commanding Officer (CO) is responsible for the conduct and tracking of all organizational-level maintenance. O-Level maintenance is conducted on a not-to-interfere-with operational tasking basis and therefore non-operational periods (availabilities) are typically not set aside just for O-Level maintenance.

b. Intermediate-Level

Intermediate-Level (I-Level) maintenance is maintenance that exceeds the resources or capabilities of ships’ force, but does not require depot-level resources or

capabilities. The Fleet Maintenance Activity (FMA) as directed by the Fleet Commander (FLTCDR) is responsible for providing the required resources and capabilities for conducting all I-Level maintenance. Additionally, submarine tenders provide I-Level maintenance capabilities specifically helpful for forward-deployed naval forces due to their mobility. At PHNSY, I-Level maintenance is conducted by the Intermediate Maintenance Facility (IMF). An I-Level maintenance period may also be called a Non-CNO Availability.

c. Depot-Level

Depot level (D-Level) maintenance consists of maintenance that requires resources or capabilities that exceed both O-Level and I-Level capabilities. D-Level maintenance must be conducted by naval shipyards or private shipyards. For submarines, this typically encompasses maintenance that requires the submarine to be in a dry-dock facility. Submarine D-Level maintenance periods are synonymous with CNO availabilities and are exclusively scheduled at naval shipyards unless naval shipyards are at capacity limits. For the purposes of this analysis, all D-Level maintenance analyzed was conducted by a public shipyard specifically PHNSY.

2. Submarine Maintenance Strategy

Both USS Los Angeles (SSN 688)-class and USS Virginia (SSN 774)-class submarines use the engineered operating cycle (EOC) strategy, which uses a combination of major and minor CNO availabilities accomplished at specified times during the submarine’s life cycle. Based on the CMP, these periodicities are established by the approved OPINTERVAL, OPCYCLE, and service life found in the submarine maintenance strategy defined below (OPNAV N9, 2013).

a. OPINTERVAL

The OPINTERVAL is the maximum duration that submarine may operate between accomplishing specific D-Level planned maintenance requirements (PMR). These PMRs must be accomplished during either a *minor or a major* CNO Availability

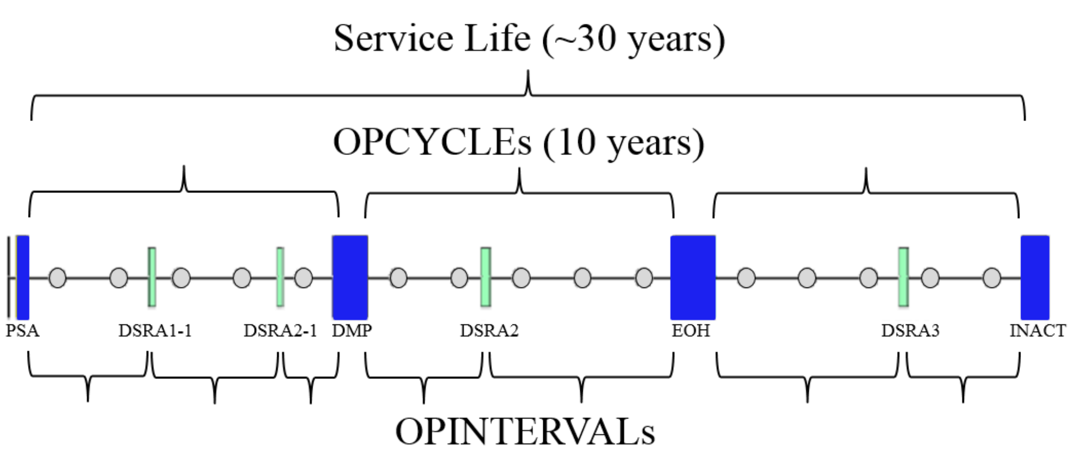
prior to end of its OPINTERVAL in order to retain its certification to conduct Unrestricted Operations (URO).

b. OPCYCLE

The OPCYCLE is the maximum duration that a submarine may operate between accomplishing specific D-Level PMRs conducted during a *major* CNO availability. SSN 688 class submarines only conduct two major CNO availabilities between activation and inactivation: Depot Modernization Period (DMP) and Engineered Overhaul (EOH) at the 10-year and 20-year point, respectively.

c. Service Life

The service life is the maximum amount of years that the submarine is allowed to operate starting the day it is delivered to the Navy. The number of major CNO availabilities and the length of OPCYCLE limit the service life of a submarine. For example, a submarine with two major CNO availabilities and an OPCYCLE of 10 years will have a service life of approximately 30 years, as shown in Figure 6.



Note: The minor CNO availabilities are colored green while the major CNO availabilities are colored blue. Each grey circle represents a 6–8 month deployment.

Figure 6. Notional Submarine Life Cycle

3. FRP and I-Level Availabilities

Between each OPINTERVAL FLTCDRs are tasked with coordinating I-Level maintenance in conjunction with training and operational requirements. The regular cycle of I-Level maintenance availabilities, training, and deployments is governed by the Fleet Response Plan (FRP). The current FRP in effect called the Optimized Fleet Response Plan (OFRP) is designed to optimize:

“1. Planned force structure and acquisition

2. Anticipated manning and resourcing levels

3. Existing and forecasted industrial base

4. Maintenance and modernization output

5. Capacity for individual and fleet training.” (COMUSFLTFORCOM/COMPACFLTINST N7, 2014, p. 1)

Technically, all SSNs have a nominal Optimized Fleet Response Plan (OFRP) cycle time of 36 months, but this stated cycle time is intended to match the 36-month cycle time for the Carrier Air Wing and only really applies to submarines attached to a Carrier Strike Group. Greater than 60 percent of SSN 688-class submarines—and the entirety of those analyzed in this report—are independent deployers that typically operate on closer to an 18- to 24-month FRP cycle.

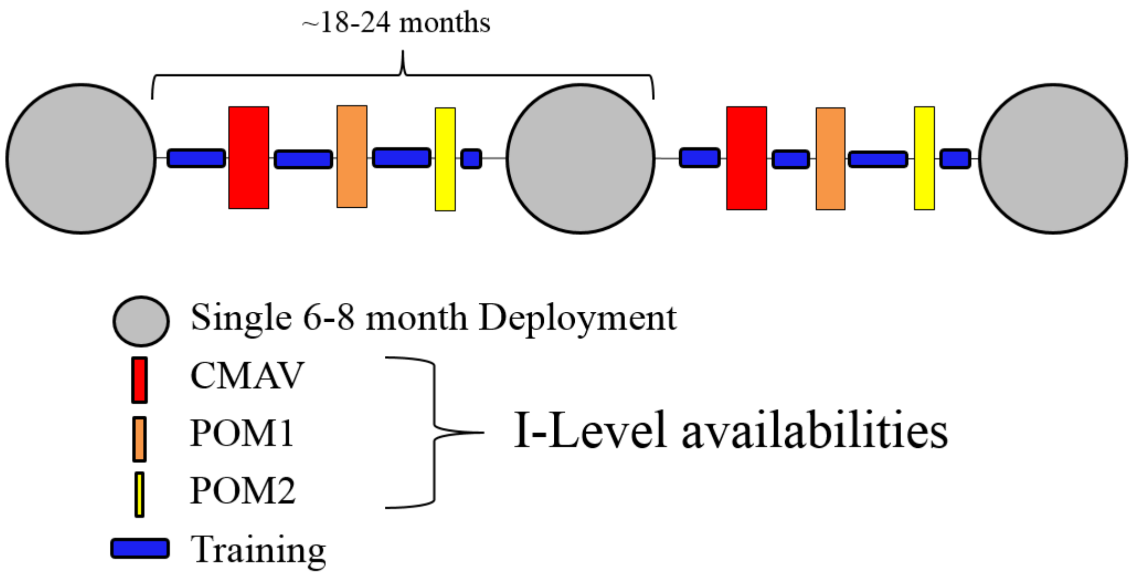


Figure 7. Simplified Notional Submarine FRP (Independent Deployer)

Typically, a submarine will have three I-Level availabilities between each deployment: Continuing Maintenance Availability (CMAV), Pre-Overseas Movement 1 (POM1), and POM2, as shown in Figure 7. This CMAV, POM1, POM2 structure is flexible with some inter-deployment periods not requiring a POM2 while others might require an additional POM3 in order to accomplish of the necessary maintenance prior to deployment. All of the inter-deployment availabilities have a combined goal to achieve all the required I-Level maintenance that will come due before the end of the next deployment.

4. Maintenance Life Cycle Changes

The Los Angeles (SSN 688)-class submarine maintenance life cycle has been updated several times in response to increased operational and updated maintenance requirements. Figure 8 illustrates the evolution of the Los Angeles class submarine notional life cycle.

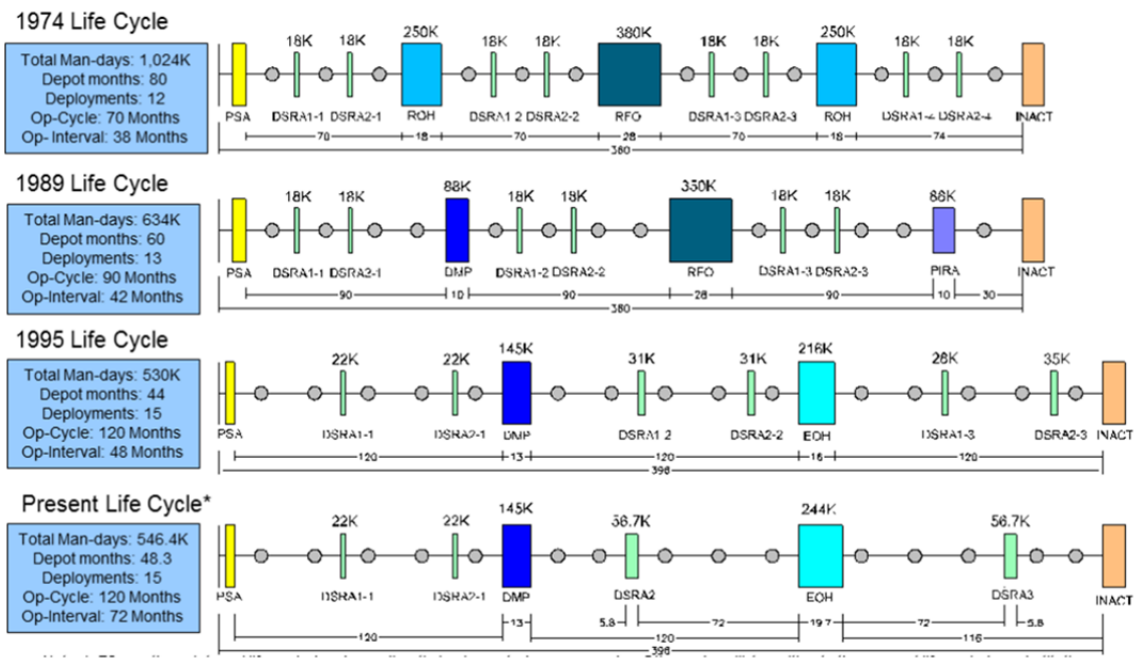


Figure 8. Evolution of Los Angeles Class Submarine Notional Maintenance Life Cycle. Source: Nawara (2013).

The most recent change to the SSN 688 class maintenance life cycle occurred in 2012 when the OPINTERVAL was increased from 48 months to 72 months. At the time of this change, all Los Angeles class submarines had already completed their first major CNO Availability called a Depot Modernization Period (DMP). The OPINTERVAL change decreases the number of minor CNO availabilities, called Docking Selected Restricted Availabilities (DSRAs), per 120-month OPCYCLE from two to one. This change effectively increases the time between maintenance of all D-Level maintenance from 48 months to 72 months (COMNAVSEASYSCOM, 2010).

B. TECHNICAL FOUNDATION PAPERS

Submarine Maintenance Engineering, Planning, and Procurement (SUBMEPP) generates Technical Foundation Papers (TFP) as the primary support maintenance strategy revisions to approved notional durations, intervals, and man-days. SUBMEPP updates these papers in order to reduce time in depot and maximize the fleet's Operational Availability (Ao). The "Technical Foundation for SSN 688 Class DSRA TYCOM Notionals, Revision A of 07 Dec 10" established the initial support for the

OPINTERVAL change from 48 to 72 months (COMNAVSEASYSCOM, 2010). This document also established the support for updated notional man-day and duration requirements for each DSRA. The current governing TFP is Rev B, which updated the notional man-days and durations without affecting OPINTERVAL or OPCYCLE.

1. TFP Rev B Duration Calculation

Using an analysis of 74 DSRAs between FY98 and FY11, studies conducted by SSN Ship Availability Planning and Engineering Center (SHAPEC), Submarine Team One, and NAVSEA assigned teams, SUBMEPP developed the equation for calculating the notional duration of SSN 688 class DSRAs shown in Figure 9.

$$\frac{(100-700\, TYCOM\ mandays\ +\ 560\, mandays)\ *\ 0.95}{964\,(\frac{mds}{week})*4.33(\frac{weeks}{month})} + 7\ week\ end\ game\ (includes\ DMD)$$

Figure 9. Current SSN 688 Class DSRA Notional Duration Calculation

From this equation, one can see that the only variable input is the amount of “100-700 TYCOM man-days.” This amount represents the total amount of non-nuclear production work planned for the DSRA. The current notional duration of 5.8 months can be found by inputting the notional value of 17,772 man-days of non-nuclear production work into the equation provided by Figure 9 (SUBMEPP, 2012). From this equation, one can infer that limiting resource in a SSN 688 class DSRA is the shipyard’s capacity to provide non-nuclear production work. The identified max “burn rate” of 964 man-days per week was obtained via historical analysis of prior shipyard DSRAs (COMNAVSEASYSCOM, 2010). An additional 560 man-days are added to the notional non-nuclear workload to account for warm water effects. The 0.95 factor represents the only change in the duration calculation from TFP Rev A to Rev B. While this 0.95 is not explained at all in Rev B, it is likely to account for the performance factor of the shipyard because the mean cost performance factor for on-time availabilities from 2005 to 2011 was exactly 0.95 (Caprio & Leszczynski, 2012). If this is the case, the factor is effectively building in extra duration to account for the efficiency of the shipyard.

Finally, a fixed 7-week end game is added to account for testing post undock. Since the change from a 48- to 72-month OPINTERVAL, most DSRAs require a Dual Media Discharge (DMD) procedure. This procedure is highly controlled and thus limits non-nuclear work for a portion of 1 week. This results in a notional DSRA duration without DMD of only 1 week less, as depicted in Figure 10.

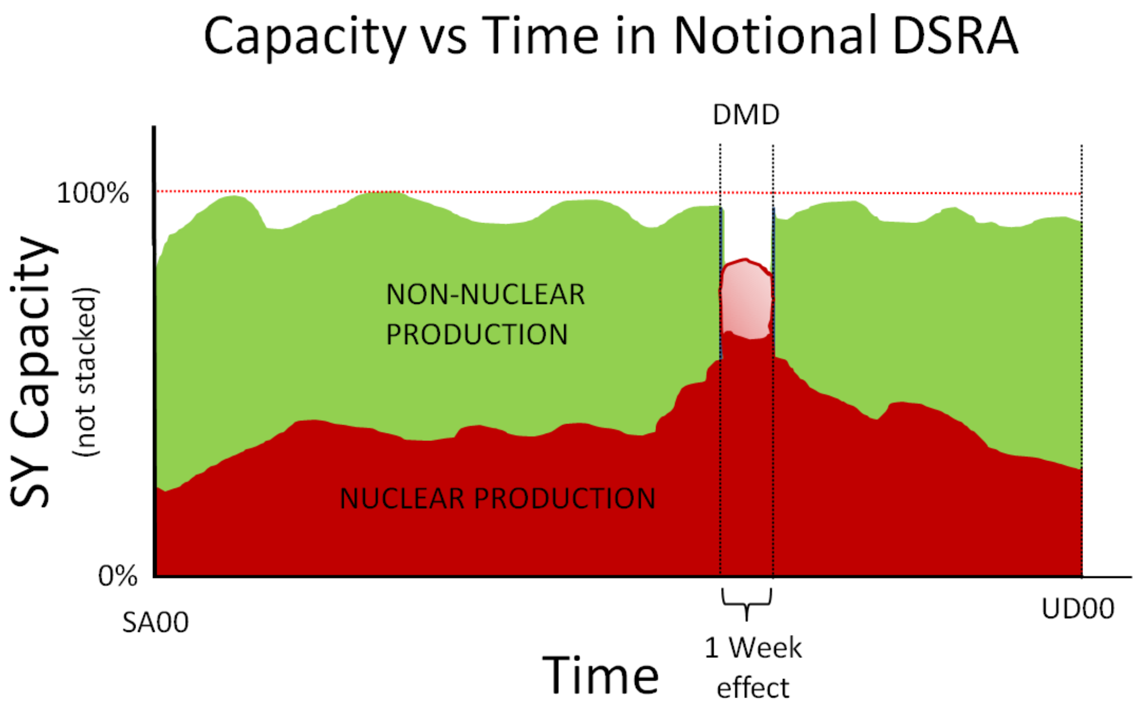


Figure 10. Notional DSRA Capacity vs. Duration Limitation (with DMD)

Deeper analysis of the 17,772 notional man-days of non-nuclear production work used to generate the 5.8-month duration estimate reveals a reliance on historical averages despite the 50 percent increase in OPINTERVAL. The total non-nuclear production work number used in the duration calculation consists of six separate categories of non-nuclear work: baseline work, fleet-wide required alterations (fleet alts), condition based/corrective actions, deferred requirements, accelerated requirements, and new work.

a. Baseline Work

Corporate Planning Estimates (CPEs) produced by SSN Ship Availability Planning and Engineering Center (SHAPEC) form the basis for updated "should cost" estimates at the line item level (SUBMEPP, 2012). These line item CPEs are combined to create the new total baseline work estimate. CPEs are validated by SHAPEC through historical trend analysis and lessons learned programs.

b. Non-Nuclear Fleet Alts

As design-related problems emerge through use, the fix to that problem may become a fleet-wide requirement if deemed proper and applicable to the rest of the fleet. These fixes called "Fleet Alts" become an additional requirement in each submarine's next availability. TFP Rev B bases non-nuclear fleet alt estimates on the average of the total fleet alts authorized for the next four *future* DSRAs at the time of TFP Rev B's release. It is reasonable to assume that the amount of design-related issues discovered per year should be in decline after the SSN 688 class having been in service since 1976, therefore, this method should be sufficient to cover future fleet-alts required.

c. Condition-Based/Corrective Actions per Maintenance Plan

NAVSEA tasks SUBMEPP to apply the concept of Reliability Centered Maintenance (RCM) through Maintenance Effectiveness Reviews (MERs). SUBMEPP continually analyzes component/system material condition data and age reliability curves to refine the appropriate balance between periodic and corrective maintenance requirements (SUBMEPP, 2012). The updated condition based/corrective maintenance requirements in Rev B are based on historical data collected from the *previous* five DSRAs. The TFP explicitly states that the updated estimate "provides an adequate amount of man-days to cover any potential increase as a result of the 72 month OpInterval" but the final man-days allotted is simply the average of the conditions based/corrective maintenance man-days required under those five *previous* DSRAs. The estimate provided is not actually adjusted away from the average to account for the OPINTERVAL change. The TFP goes on to state that the "CPE will be re-addressed as more DSRAs are accomplished on submarines after completing a 72 month OpInterval"

yet no such re-evaluation has been approved since Rev B's approval in 2012 (SUBMEPP, 2012).

d. Deferred Requirements

Deferred requirements are requirements that were originally scheduled for completion in a previous availability but were deferred to the DSRA having been deemed safe to do so by technical experts. This estimate is similarly based on the average man-days required under the *previous* five DSRAs.

e. Accelerated Requirements

Accelerated requirements are requirements that must be done early in order to prevent loss of certification prior to the next available maintenance window. TFP Rev B again uses the average of the previous five DSRAs as its CPE.

f. New Work

Surprisingly, the largest component of work other than baseline work is similarly unadjusted for the 48 to 72 month OPINTERVAL change. New work is calculated as a percentage of the subtotal comprised of the baseline work, non-nuclear fleet alts, condition based/corrective actions per maintenance plan, deferred requirements, and accelerated requirements. The average of new work percentages found in the *previous* five DSRAs is used as the updated CPE for new work. Those five DSRAs were conducted having previously operated under the 48-month OPINTERVAL yet the CPE does not account for any growth in new work under the 72-month OPINTERVAL. The analysis used to determine the new work percentage for future DSRAs operating under the 72-month OPINTERVAL is shown in Figure 11.

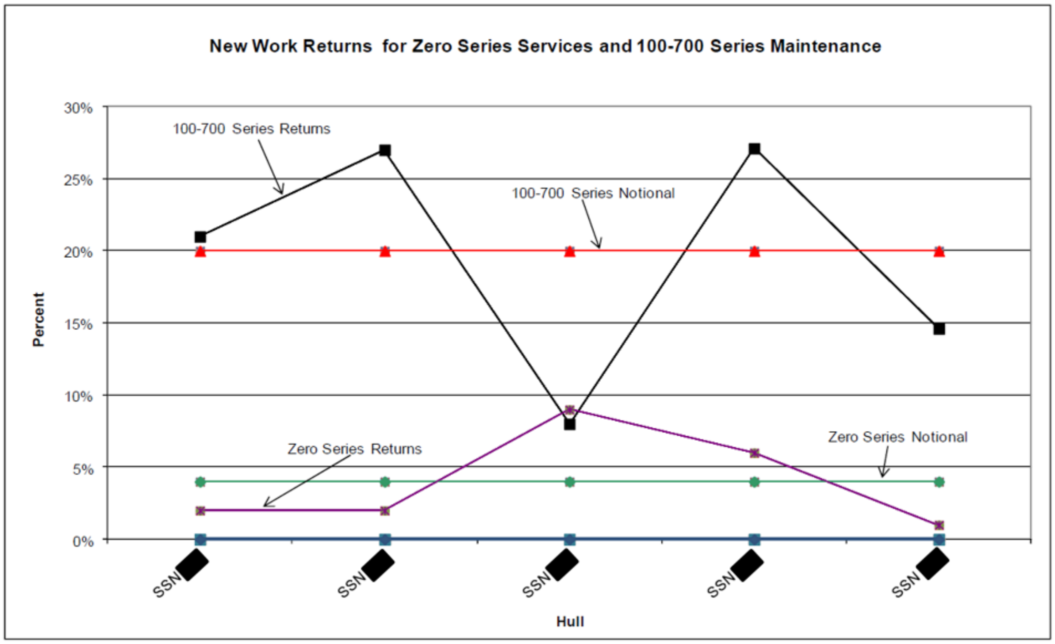


Figure 11. TFP Rev B Non-nuclear New Work Budget.
Adapted from SUBMEPP (2012).

2. TFP Duration Summary

The current TFP Rev B exclusively uses the amount of non-nuclear production work as the sole input for total DSRA duration calculations. In doing so, all estimation techniques used to estimate the notional non-nuclear production workload directly affects the resulting notional duration. When SUBMEPP went from the 48-month to 72-month OPINTERVAL, they used historical averages to estimate condition based maintenance and new work allotments. One could argue that condition-based maintenance and new work should increase at a rate greater than pro rata with increased time between maintenance, yet these numbers have not been updated since the change to a 72-month OPINTERVAL. An update to these CPEs would result in an increase to the notional DSRA duration that may explain, at least partially, some of the duration issues observed.

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III. DATA AND KEY ASSUMPTIONS

A. DATA COLLECTION

Collecting all the data required to conduct an analysis proved extremely difficult due to the divergent variables maintained by each stakeholder in the submarine maintenance world. For example, the SUBPAC N4 shop preserves data pertaining mostly to schedule while the Naval Shipyard & Intermediate Maintenance Facility (IMF) retains more budget and cost-related data. SUBPAC N4 proved to be the most responsive to requests for data due to this research being a genesis of SUBPAC N4's specific inquiry. As a result, approximately 80 percent of the data collected was from the historical databases maintained within the SUBPAC N4 shop itself.

1. I-Level Availability Data Collection

a. SUBPAC N4

I-Level maintenance availability data maintained at SUBPAC N4 was only available during two distinct periods; from 2001 to 2006 and from 2014 to 2017. An explanation for the gap in data is unavailable and provides an example of the need for a combined data collection effort explained further in Chapter VI.C.1. I-level data included 123 availabilities from 2001 to 2006 and 103 availabilities from 2014 to 2017.

Variables per availability collected: (example provided following the colon)

1. Immediate Superior In Command (ISIC): CSS-1
2. Ship Name: USS NAME
3. HULL: SSN ###
4. Start Date: 11/8/2016
5. End Date: 12/11/2016
6. Duration (days): 34
7. Location: Pearl Harbor

8. Type of Availability: POM1

9. Days Late (days): 2

10. Cost Expended: $930,346

11. Man-Days Total: 1,867

12. Jobs Total: 191

13. Jobs Deferred: 42

14. Jobs Cancelled/Rejected: 16

15. Jobs Completed: 129

b. PHNSY and IMF

An unpublished study conducted by PHNSY and IMF covering FY08 to FY14 was able to provide a portion of the gap in SUBPAC N4 data (PHNSY & COMSUBPAC, 2015). For the 193 I-Level maintenance availabilities included in the PHNSY and IMF study, only total duration and total man-days used was available as opposed to SUBPAC N4's data which had many more variables such as the number of days late and the number of jobs completed.

Variables per availability collected: (example provided following the colon)

1. Hull #: ###

2. Boat Name: NAME

3. Availability Type: POM2

4. Start Date: 1/4/2011

5. End Date: 2/09/2011

6. Man-Days Total: 1,321

2. D-Level Availability Data Collection

Data for all D-Level maintenance was obtained via the same PHNSY & IMF study (PHNSY & COMSUBPAC, 2015). That study included 27 total D-Level availabilities from 2008 to 2017, of which 15 were SSN 688 class DSRAs.

Variables per availability collected: (example provided following the colon)

1. Shipyard: PHNSY
2. Ship: NAME
3. Hull: SSN ###
4. Availability Type: DSRA
5. Cost Performance (CP): 0.89
6. Start Date (SA00): 1/14/2008
7. End Date (CA00): 6/14/2008
8. Day's Late (days): 0
9. Total Duration (days): 152
10. 0's Quantity at Completion (QAC): 2,644
11. 0's Actual Quantity of Work Performed (AQWP): 2,611
12. 1-7's (QAC): 15,490
13. 1-7's (AQWP): 19,367
14. 8's (QAC): 5,635
15. 8's (AQWP): 6,187
16. 9's (QAC): 20,471
17. 9's (AQWP): 22,447
18. Total QAC: 44,240
19. Total AQWP: 50,612

Variables 10–17 above are all a quantity of work as measured in man-days. Those variables are labeled at their Ship Work Line Item Number (SWLIN) series level shown in Table 1.

Table 1. SWLIN Series Descriptions

SWLIN Series	Series Major Ship System
000	Support Services
100	Hull structure and appurtenances
200	Propulsion
300	Electric plant
400	Communication and control
500	Auxiliary systems
600	Outfitting and furnishings
700	Armament
800	Nuclear
900	Project Management/Admin

Combined 100–700 SWLIN Series represent total Non-Nuclear Work.

B. DATA NORMALIZATION

1. Normalization for Content

Certain maintenance availabilities were omitted from analysis based on several criteria. First, all non-Los Angeles class submarine availabilities and non-PHNSY availabilities were eliminated as discussed under the analysis strategy. This step eliminated more maintenance availabilities from the 2015–2017 period of data because more of those availabilities were done on the newer Virginia class submarines. Second, only the same type of availability was compared for D-Level availabilities. For example,

of 27 D-Level availabilities there were 15 DSRAs, 4 PIRAs, 3 EOHs, 2 DMPs, 1 IA, 1 ERO, and 1 EDSRA. All of these availabilities are named differently because they inherently have different amounts and types of maintenance in each one. To compare data points from an EOH and a DSRA would not be meaningful because an EOH is a major CNO availability while a DSRA is a minor CNO availability. Therefore, the D-Level data analysis uses only the 15 DSRA type availabilities. I-Level availabilities also had a variety of names such as FMAV, CMAV, POM1, POM2, however all types are used in the analysis. I-level availabilities work in a series together under the FRP to prepare the submarine for each deployment. Additionally, I-level availability names are more a convention of time in the FRP than of the work inherent in the availability. Therefore, by including all types of I-level maintenance, we can get a look at the trends associated with I-level maintenance as a whole.

Finally, a common-sense test was applied to significant outliers eliminating a small amount of availabilities from the analysis. An example of this common sense test was an availability that had a "Duration" statistic of 5 days but a "Days Late" Statistic of 30 days. The availabilities total "Duration" is available by subtracting the actual start date from the actual end date. Any number of "Days Late" should be included in this period and therefore must be less than the total duration. Therefore, for common sense purposes, availabilities with statistics failing these basic checksums were removed from the analysis. After applying all three criterions, 328 I-Level availabilities are available for I-Level analysis.

2. Normalization for Quantity

This analysis does not normalize the data for quantity because the theoretical quantity of maintenance should remain constant over time. Variations in quantity of maintenance accomplished per availability should be corrected for via "big data" (the large number of data points used). The data is automatically corrected for the decreasing number of operational submarines over time by looking at quantities on a per availability basis only. Any significant trends associated with the quantity of maintenance per

availability is independent of the total number of operational submarines and would indicate a primary finding in it of itself.

The change to the total number of DSRAs per 10 year OPCYCLE (from two to one) does not lower the shipyards over-all workload because the newer DSRAs are increased in work and duration. In addition, shipyards are staffed and funded based on estimates of future needs so increases and decreases in shipyard-wide future workloads are proportionately staffed and funded to those levels.

3. Normalization for Inflation

This analysis normalizes all cost data collected for inflation using the Naval Center for Cost Analysis (NCCA) Inflation Indices and 2016 Joint Inflation Calculator (JIC). Using the JIC, all cost data is normalized from Then-Year $ to Constant FY16 $. Due to inflation alone it is expected that maintenance costs will increase over time so by normalizing all the cost data to FY16 $, this allows us to look at real cost growth over time.

C. KEY ASSUMPTIONS

Due to the disparate data sources and the large gap in data previously mentioned, two assumptions are necessary in order to allow for an effective data analysis.

1. Statistic Relevance over Time

Some data points could have different meanings when compared across two periods. However, this analysis treats all such data points as having the same meaning over time. For example, a statistic like the number of “Jobs Completed” may not be a pure comparison between periods because the meaning of a “Job” may have evolved over time. In this instance it is possible that the same “Job A” in 2002 may be equivalent to two sub-jobs (Job A.1 and Job A.2) in 2016. In order to rule out these definition errors an in-depth analysis into the job-level maintenance is required which is outside the scope of this analysis.

2. New Work Causes Late Days

An investigation into the cause of overruns in maintenance availability durations necessitates the assumption that unexpected new work or re-work is the genesis of the vast majority of late availability days. Discussions with submarine maintenance experts confirms the assumption that almost all late days are a direct result of new work generated in the critical path of the availability or late enough in the availability to become the critical path. The submarine maintenance community generally accepts this assumption as fact (SUBPAC N4, 2017). This assumption also allows the analysis to look at factors that may cause new work or re-work to occur in order to find the root cause of the duration overruns themselves.

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IV. INTERMEDIATE LEVEL MAINTENANCE ANALYSIS

A. PROBLEM VERIFICATION

After collecting all the data from different sources, collating, and normalizing for content, quantity, and inflation, the first step in attacking the problem is to verify the primary issue. After initial discussions with SUBPAC N4, it was not initially clear whether the main problem related to the cost, schedule, or performance of the maintenance availabilities.

1. Cost

The FY16 $-adjusted cost of each I-Level availability is first investigated. Figure 12 shows the total cost per SSN 688 class submarine I-Level availability conducted at PHNSY.

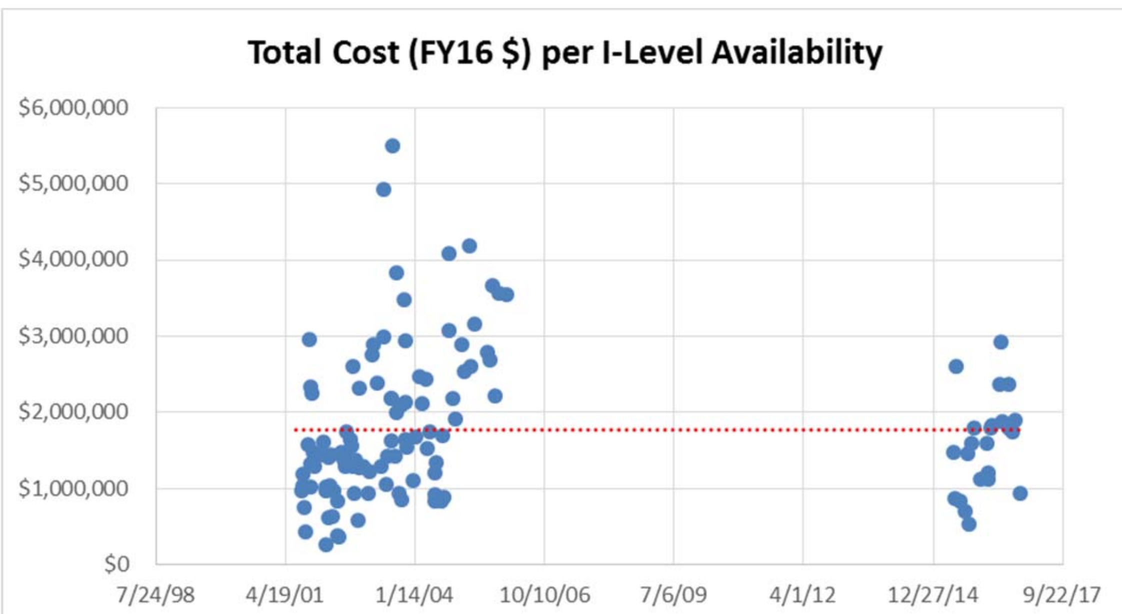

Figure 12. Total Cost per I-Level Availability

Contrary to depot level maintenance (Figure 5), the average cost of I-Level availabilities has remained constant after adjusting for inflation (Figure 12). In fact,

further analysis shows that the real average cost of labor as measured in man-days has slightly declined as seen in Figure 13.

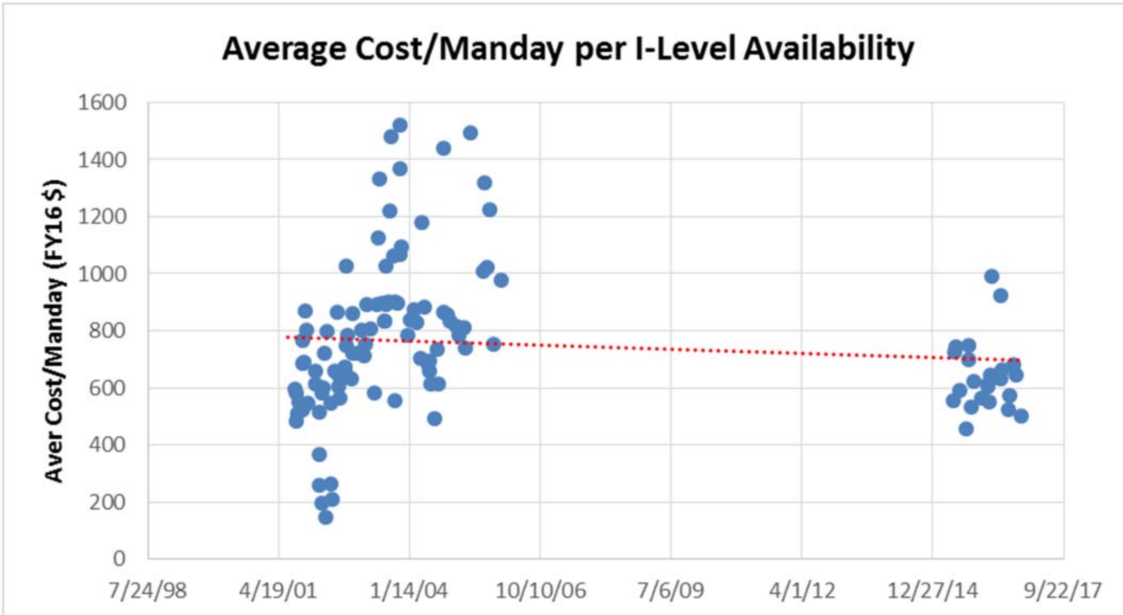

Figure 13. Average Cost of Labor per I-Level Availability

2. Schedule

Next, the schedule adherence of each availability is investigated. Maintenance activities are normally judged on number of days behind schedule. This metric results in the number of days late per availability shown in Figure 14.

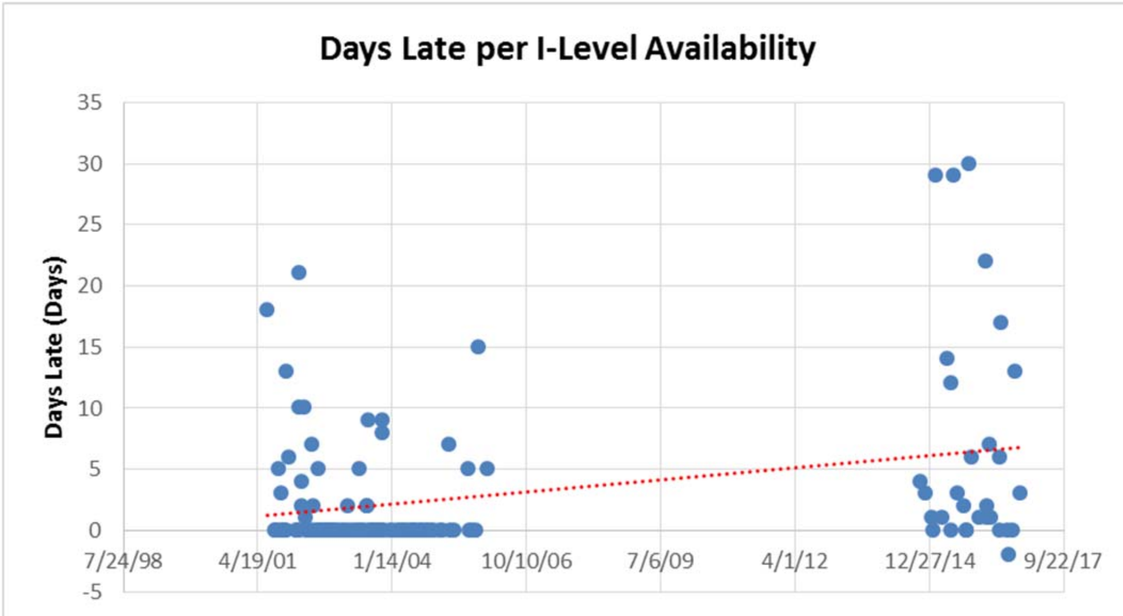

Figure 14. Days Late per I-Level Availability

The total number of days late per availability has increased from an average of 2.05 days late per availability in 2001–2006 to an average of 7.66 days late per availability in 2015–2017. Additionally, there has been an increase in the variability of days late, as shown by the histograms presented in Figure 15.

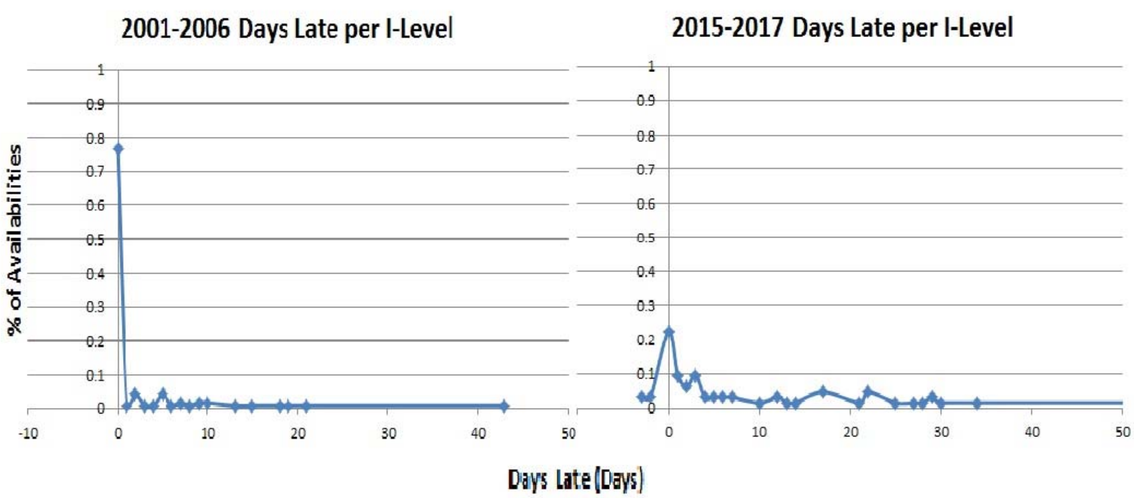

Figure 15. Days Late per I-Level Availability Histogram Comparison

Figure 15 also shows at the y-intercepts how 76.7 percent of I-Level availabilities from 2001–2006 were completed on time (0 Days Late) as opposed to only 22.6 percent of availabilities completed on time from 2015 to 2017. Based on discussions with SUBPAC N4 experts and an analysis of several after action reports, this thesis concludes that the increase in late days is a result of an increase to the amount of new work encountered during the availability affecting the critical path. One opposing hypothesis regarding this increase in late days is that the increase is simply due to a stricter adherence to initial duration baselines. If this were the case, however, then we should see an increase to late days without a corresponding increase to the total availability duration. The positive trend to the total duration per availability shown in Figure 16 helps rule out this possibility.

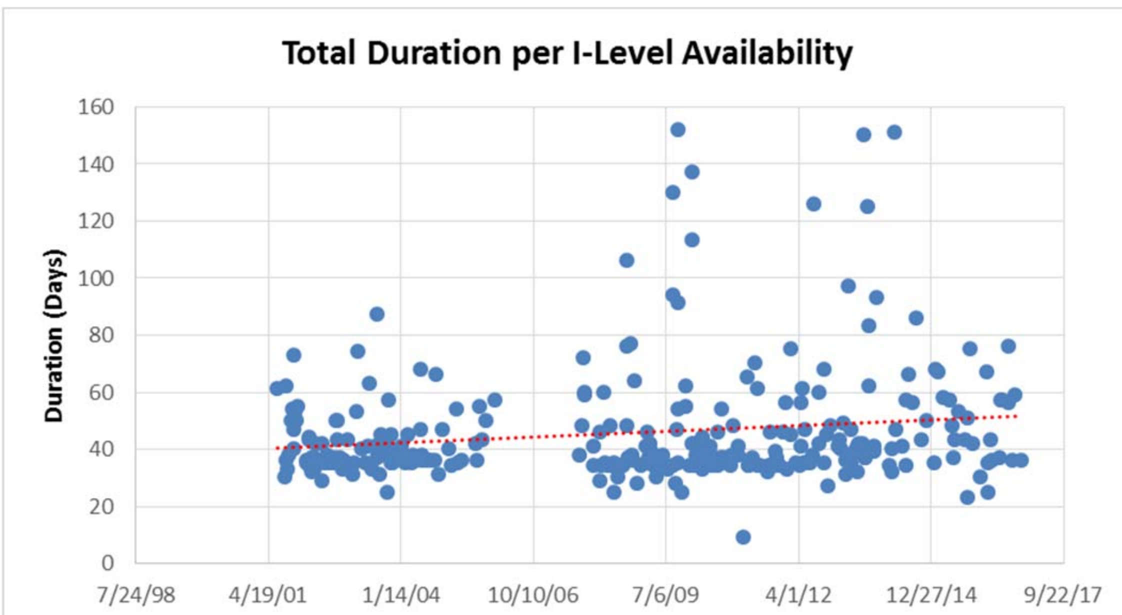

Figure 16. Total Duration per I-Level Availability

By subtracting the number of days late from the total duration, we can calculate a theoretical "scheduled" duration for each availability shown by the green in Figure 17. A stricter adherence to scheduled baselines cannot wholly account for the increase in late days because the "scheduled" duration has a near zero trend over time.

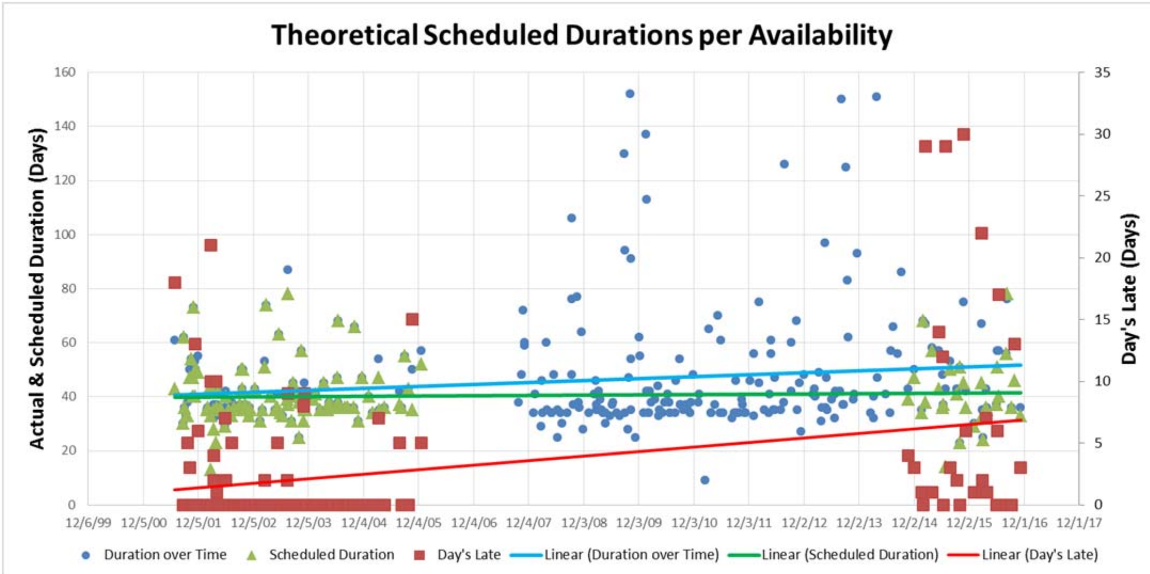

Figure 17. Actual & Theoretical Scheduled Durations

The increase in total duration shown in blue above the "planned duration shown in green corresponds with the overall increasing trend of late days shown in red (Figure 17).

3. Performance

Finally, we measure performance data to see if negative trends exist. All of the availability performance reports collected measured shipyard performance via the cost performance (CP) ratio, which is the Budgeted Quantity of Work Performed (BQWP) divided by the Actual Quantity of Work Performed (AQWP). The CP is also commonly referred to as the shipyard performance factor or "SY PF" on reports such as the required completion message sent by shipyard via official message traffic (NAVSHIPYD AND IMF PEARL HARBOR HI, 2014). SUBPAC N4 however does not maintain this data at the I-Level. An alternate way to measure performance, contained within the available data set, is to measure the total number of jobs completed per availability shown in Figure 18.

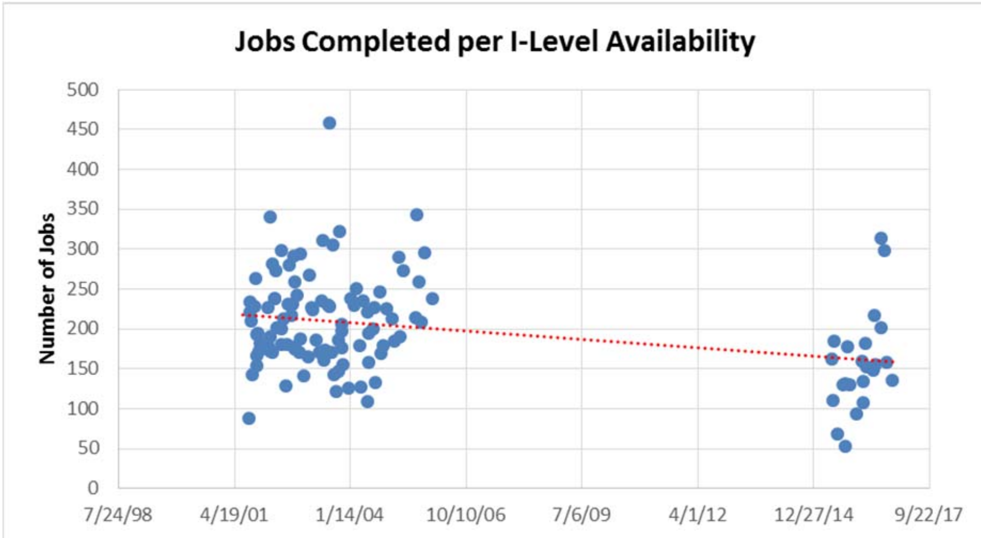

Figure 18. Jobs Completed per I-Level Availability

This measure does not take into account differing availability lengths so the better measure for performance available would be the average jobs completed/day per I-level availability shown in Figure 19.

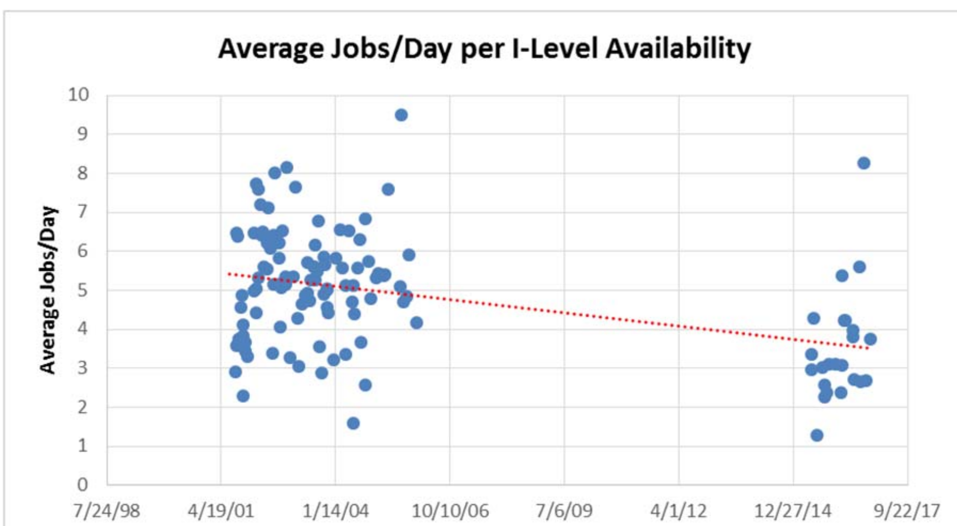

Figure 19. Average Jobs/Day per I-Level Availability

The average jobs completed per day has dropped 1.68 jobs/day from a mean of 5.22 jobs/day in 2001–2006 to a mean of 3.51 jobs/day in 2015–2017. Figure 20 shows how many of the jobs not completed are being deferred or cancelled.

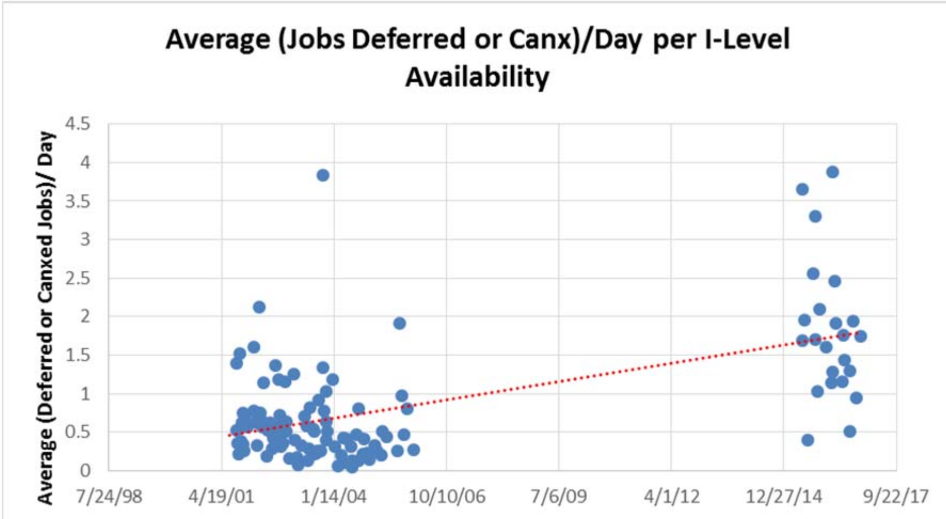

Figure 20. Average (Deferred or Canceled Jobs)/Day per I-Level Availability

The average jobs deferred or cancelled per day has increased 1.2 jobs/day from 0.6 jobs/day in 2001–2006 to a mean of 1.8 jobs/day in 2015–2017. The 1.2 jobs/day increase to deferred or cancelled jobs accounts for 71 percent of the corresponding decrease in job completion. This indicates that the decrease in the number of completed jobs is not due to a decrease in maintenance requirements (conceivably from better maintenance practices). The daily job completion and deferral rates shown in Figures 19 and 20 alone could simply show that there is an increase to total availability durations without any change to workforce capability/performance. The incorporation of the decreasing total job completion shown in Figure 18 with increasing average duration shown in Figure 16, however, indicates that there has been either a decrease in workforce capability/performance or an increase in job complexity. Figures 21 and 22 show how IMF has executed the same average number of man-days per day but how each job has taken significantly more man-days to complete.

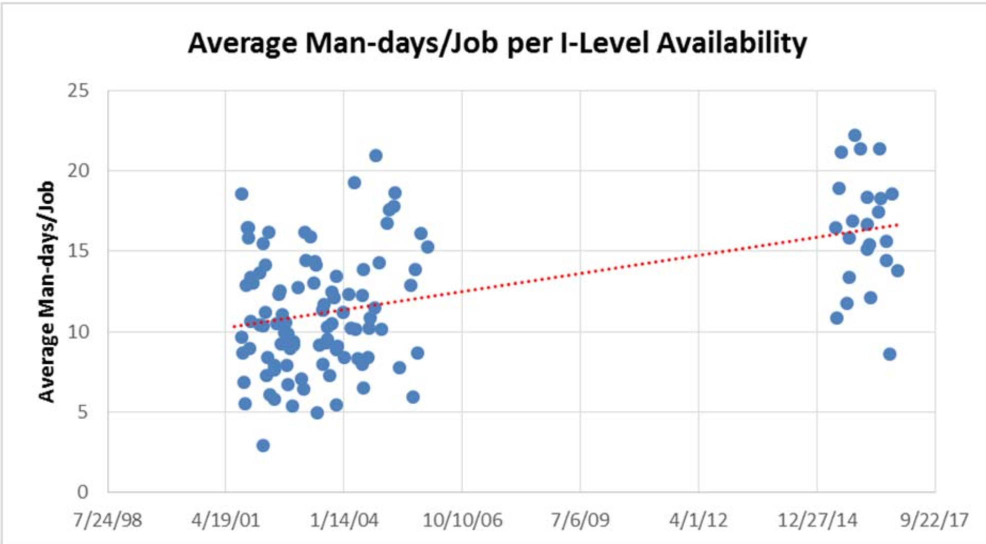

Figure 21. Average Man-days/Job per I-Level Availability

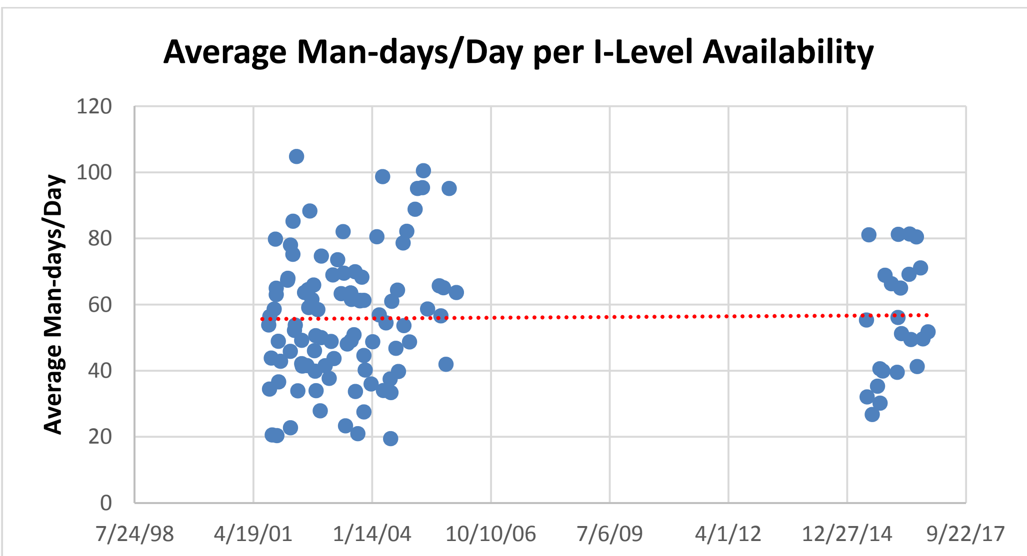

Figure 22. Average Man-days/Day per I-Level Availability

The average man-days/job has increased 5.2 man-days/job from 11.09 man-days/job in 2001–2006 to 16.29 man-days/job in 2015–2017. The 46.7 percent man-day per job growth indicates either:

Decreased workforce efficiency due to less experienced workforce.

Decreased workforce efficiency due to less resources (budget driven).

Increased job level complexity without lowering PMRs such as increased safety requirements per job.

Figure 22 indirectly indicates that staff levels have remained constant; therefore, the decrease in workforce efficiency is more likely due to workforce experience levels as opposed to staffing levels. Explicit staffing level data would better prove this assertion. The best way to distinguish between the possible sources of increased man-days/job is to dig into the job level data. A comparative analysis of the same job's complexity and man-days required over time could illuminate the existence of "man-day creep" (the process of incremental increases in the man-days required to complete the same job). This analysis is beyond the scope of this thesis but is recommended for future studies. As mentioned earlier, this analysis chooses to assume the statistical relevance over time of all variables therefore eliminating the job level complexity increase possibility.

4. Summary

From 2001 to 2017, both schedule and performance have degraded in SSN 688 class submarine I-Level maintenance availabilities. With a notionally static FRP, the originally scheduled duration of I-Level availabilities has remained the same while actual duration has increased proportionately with an increase in late days. Our analysis indicates that each job is taking more man-days to complete resulting in less jobs completed and more jobs being deferred or canceled per day of availability. The primary suspects causing this decrease in workforce efficiency are a less experienced workforce and/or a lack of available resources at the I-Level.

B. KEY INDEPENDENT FACTORS

The primary independent factors available for analysis on the I-level data are the submarine age at the availability and the availability start date. The previous problem identification process provided negative trends in schedule and performance. Distinguishing which independent variable is the primary driver for these trends is difficult because our two independent variables (the average age of SSN 688 class

submarines at the time of each availability and the date of the availability) are highly correlated as shown in Figure 23.

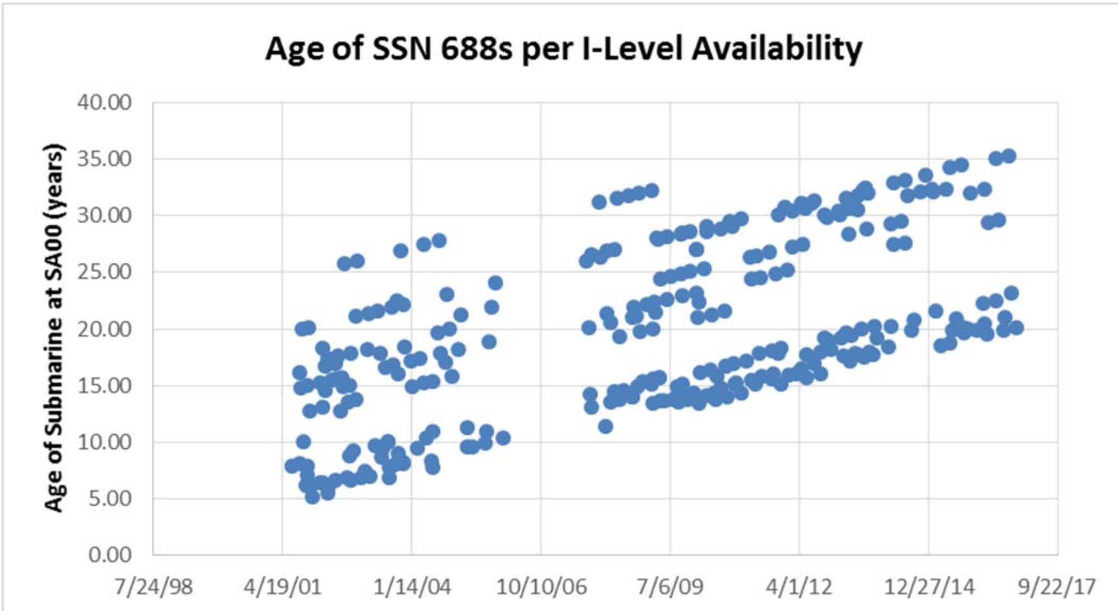

Figure 23. Age of SSN 688s at SA00 over Time

In order to distinguish whether issues tied to the date, or the age of the submarine itself, are causing the negative maintenance trends we observed, regression analyses were performed against three dependent variables: total duration, number of days late, and man-days/job. The resulting "p-values" of regression obtained in each of the following regression analyses represent the probability that the correlation has no significance. For example, the regression analysis of the age of a submarine at the time of the availability and the date of the availability yields a "p-value" of zero. This means that there is zero percent chance that they are completely independent of each other as we can see visually in Figure 23. Conversely, a regression analysis of the age of a submarine and the month number (e.g. 12 for December) that the availability starts is completely random and yields a "p-value" of 0.28. This means that if we reject the hypothesis of independence, we have a 28 percent chance of error. Since the typical threshold for describing the relationship as statistically significant is 0.05 or a 5 percent probability (Berger & Sellke, 1987), we do not reject the independence hypothesis.

1. Schedule

First, the duration of each availability is compared against the age of each submarine at the start (SA00) of that availability. There is a definite correlation between age and duration with a "p-value" of regression of 0.00569. Thus, we may reject the hypothesis that correlation between age and duration is zero.

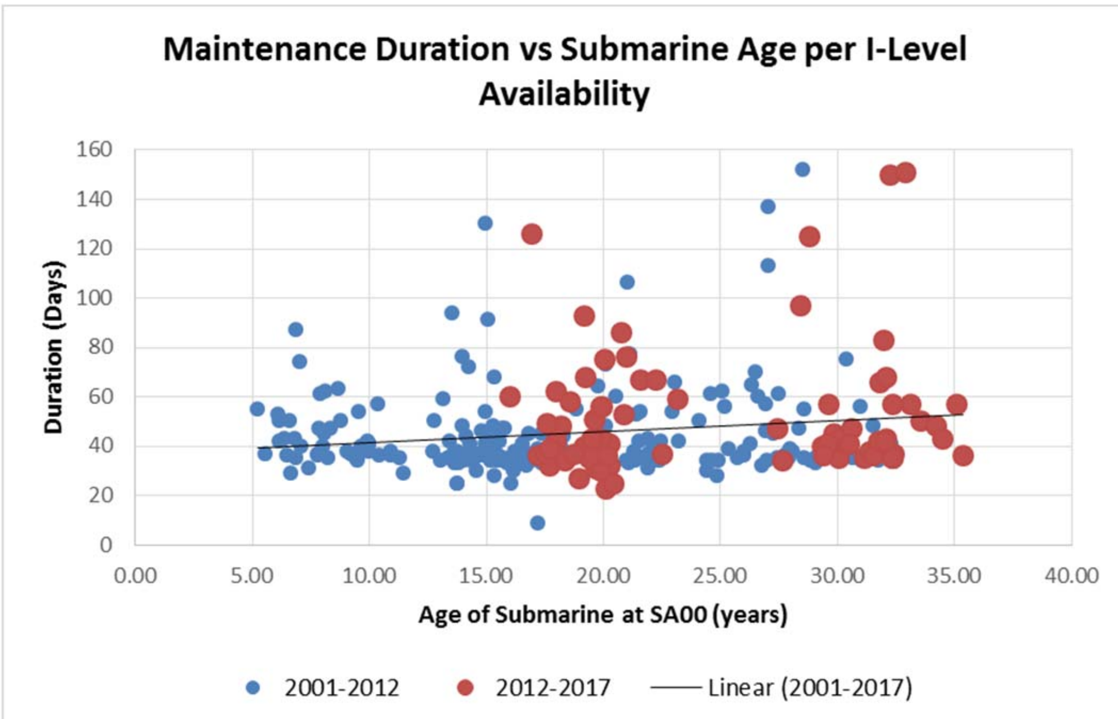

Figure 24. Maintenance Duration vs. Submarine Age per I-Level Availability

A similar relationship exists between duration and the date of the availability. The 0.0061 "p-value" of regression between duration and date gives a 0.601 percent chance of zero correlation.

The correlation between age and the number of late days is less strong having a "p-value" of 0.125 meaning that there is a 12.5 percent chance that late days and age have zero correlation. The relationship between the number of late days and the date of availability indicates a "p-value" of 0.000197. Therefore, the chances that the date of the

availability and the number of days late of the availability have no relationship is only 0.019 percent.

2. Performance

As discussed in section A.3 of this chapter, a primary finding associated with the decreased performance trend is the increase in average man-days/job. The average man-days/job versus age regression yields a “p-value” of 0.001345 while the average man-days/job vs date yields a “p-value” of practically zero (3.18E-09). This analysis shows that factors associated with the date of the availability are more slightly likely to be associated with late days as opposed to factors associated with a submarine’s age at the time of the availability.

3. Summary

Regression analysis shows strong relationships between both independent factors analyzed and the problems identified in section A of this chapter. A summary of the regression analysis:

Regression Analysis "p-values"

	Age	Date
Duration	0.00569	0.006017
Days Late	0.125	0.000197
Average Man-days/Job	0.001345	3.18E-09

Figure 25. Age and Date Regression Analysis “p-values”

The only p-value that does not meet the typical threshold of 0.05 is the relationship between the age of the submarine and the number of days late and age. This means that a regression of the number of days late vs age alone is not statistically significant. In other words, the increase in the age of the submarine alone cannot accurately account for the increase in days late. Unfortunately, the fact that both independent factors are so highly correlated and that all the other p-values are so close

prevents further distinctions. Planners do not explicitly allow longer duration for maintenance as the submarine gets older. One possible reason why the relationship between the age and days late fails to be significant is due to the lack of late day data available from 2006–2014. While this analysis is unable to eliminate age as a contributing factor to the issue, it does help dismiss age as the sole culprit to the increase in days late observed as well as provide a “more likely” direction for future studies.

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V. DEPOT LEVEL ANALYSIS

A. SCHEDULE AND PERFORMANCE TRENDS

Analysis of SSN 688 class DSRAs conducted at PHNSY from 2008 to 2015 shows decreasing schedule and performance trends.

1. Performance

The D-Level data collected on SSN 688 class DSRAs at PHNSY contains Quantity at Completion (QAC) and Actual Quantity of Work Performed (AQWP) variables as reported in man-days. QAC represents the total budget for the availability. The original QAC is initially set by the Final Review Estimate (FRE) at the Final Planning Meeting. These numbers are notionally based on the TFP but are increased due to actual Preventative Maintenance Requirements (PMRs). Throughout the availability, the official QAC must be changed when certain duration and cost thresholds are exceeded. This updated QAC called the FRE-rebaseline is used as the overall budget for the rest of the availability (R. Ryglowski, personal communication, April 21, 2016). Therefore, in the data collected, the QAC numbers represent the updated FRE-rebaseline as opposed to the original baseline set at the Final Planning Meeting.

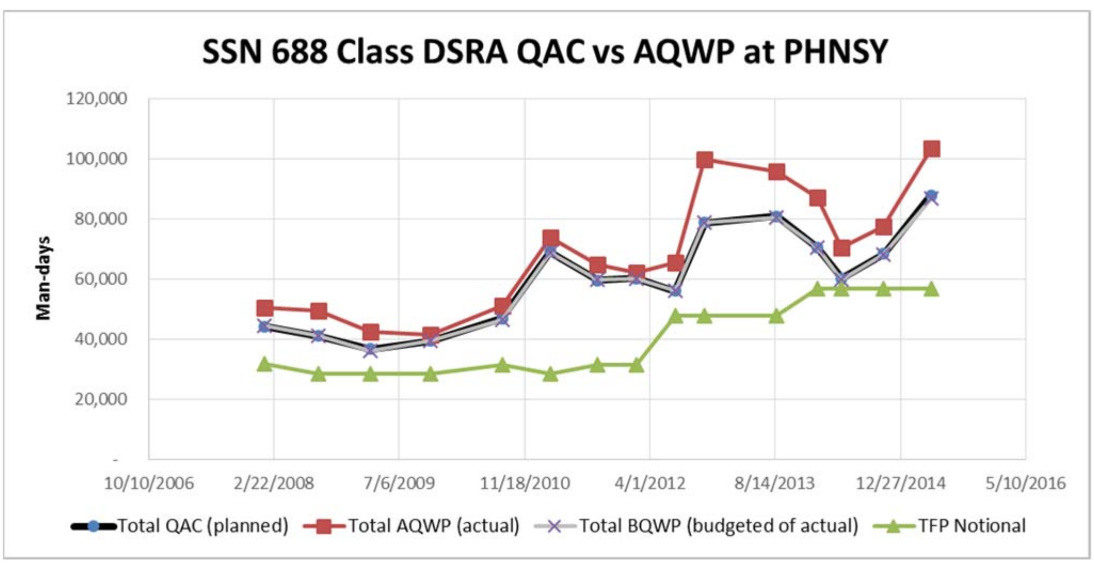

Figure 26. SSN 688 Class DSRA Man-Days at PHNSY FY08–FY15

Figure 26 shows how the AQWP is consistently higher than QAC and the TFP notional man-days. The Budgeted Quantity of Work Performed (BQWP) represents the notional man-days for the jobs that were actually completed or, said another way, the actual amount of work that was completed. If the availability completes 100 percent of the jobs agreed to at the Final Planning Meeting and no additional jobs then the BQWP will equal the QAC. The BQWP to QAC ratio is used to determine the overall progress of the availability because it represents how much actual work has been completed divided by the total planned work. The ratio of BQWP to AQWP called the Cost performance Ratio (CP) is used to evaluate shipyard performance because it represents how much work has actually been completed divided by the actual cost of the work completed (J. Tappe, personal communication, April 21, 2016). This CP ratio, however, does not reflect how much of the originally planned work was actually completed. Theoretically, the BQWP divided by the original QAC would show this but the aforementioned practice of continuously updating the QAC prevents this from being accurate (R. Ryglowski, personal communication, April 21, 2016).

Any new work that exceeds the original new work budget will increase the BQWP. If a job initially planned for completion at the Final Planning Meeting is deferred or cancelled, this lowers the BQWP. The practice of continuously updating QAC with each re-baseline causes the final BQWP to match the final QAC as seen in Figure 26. Therefore, unless shipyard executes at a perfect CP of 1.0 or more, AQWP will always be over budget (QAC).

Figure 27 shows the CP ratio and over execution percentages to show how CP closely mirrors over-execution due to the practice of matching final QAC and final BQWP. Notice the sharp spike (or performance decrease) in FY2012 that corresponds with when PHNSY first started implementing the OPINTERVAL shift from 48 months to 72 months.

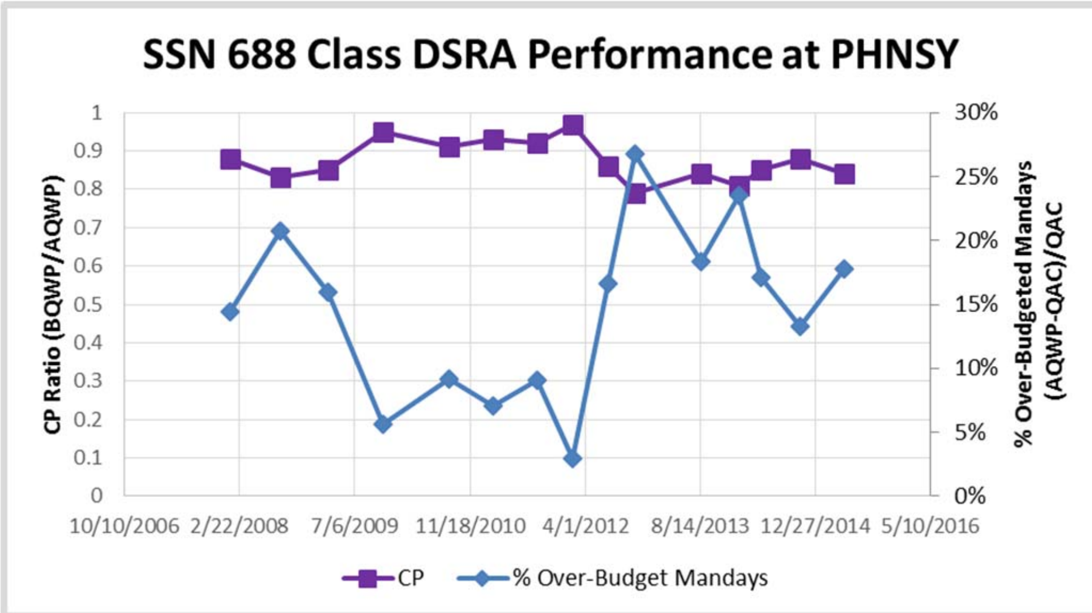

Figure 27. SSN 688 Class PHSNY DSRA Availability Performance FY08-FY15

Unfortunately, when the QAC is re-baselined the only way to determine the original baseline for data analysis purposes is to pull it from the official DSRA Final Review Estimate letter for each availability. We do not attempt to pull this data for each availability but future studies could usefully look at this issue.

2. Schedule

Figure 28 shows planned and actual durations in dark blue and green, respectively. The light blue shows the notional duration according to the applicable TFP at the time of the availability. Note that the TFP notional duration is non-constant prior to the 72-month OPINTERVAL shift in 2011 made by TFP Rev A. Under that TFP, DSRAs were given different notional durations and man-days depending on their number in the series of DSRAs (1-2, 2–2, 1–3, 2–3).

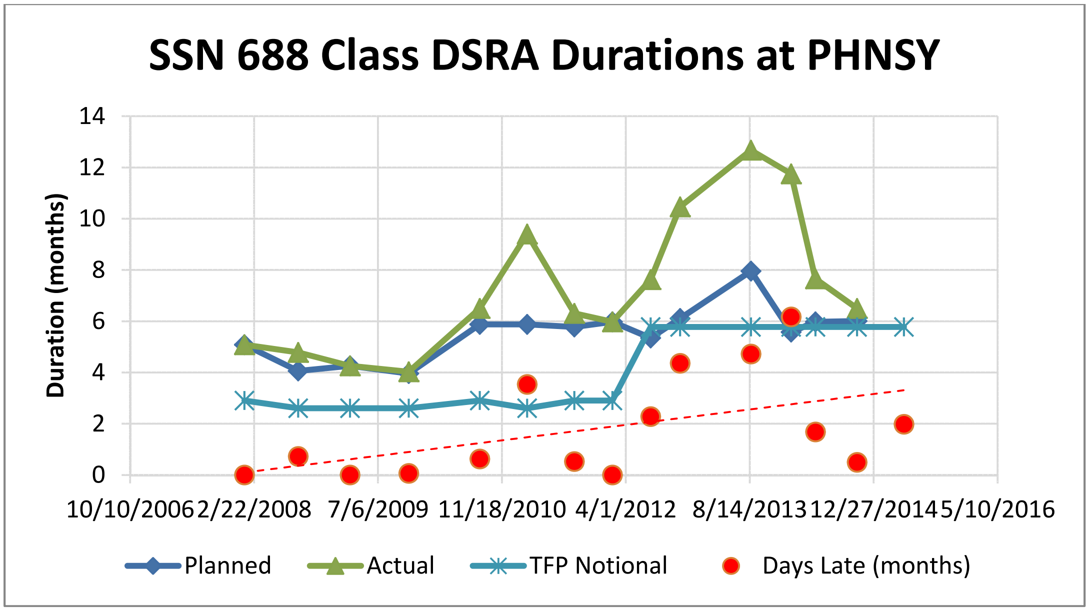

Figure 28. SSN 688 Class DSRA Durations at PHNSY FY08-FY15

Additionally, note the greater than four-fold increase in average number of days late shown in red.

As opposed to the performance metrics, the "planned" duration from which Late Days are measured represents the original CNO planned days as determined at the Final Planning Meeting. As a result, Performance and Schedule are not compared equally because Performance is compared against the approved re-baseline while schedule is compared against the original FRE duration.

B. NOTIONAL DURATION APPLICATION

With each update to the SSN 688 class DSRA TFP, DSRA planners use the equation provided by the governing TFP document to calculate the planned duration. The recent evolution of these equations is depicted in Figure 29.

48-month OPINTERVAL	Prior TFP	$\text{Duration} = \frac{\text{A+ B–C (Man-days)}}{\text{9,456 maximum man-days/month}}$ A = Total 000-900 series SWLINs B = Warm water effects C = Onyard services and offyard travel adjustments	2.6-3.3 months baseline
72-month OPINTERVAL	TFP Rev A Used ~ early 2012	$\frac{(100-700\ \boldsymbol{TYCOM\ mandays} + 560\ \boldsymbol{mandays})}{964\ (\frac{mds}{week})*4.33(\frac{weeks}{month})}$ $+1\ \boldsymbol{m\ end\ game} + 1\boldsymbol{m\ DMD}$	5.8 months baseline
	TFP Rev B Used ~ late 2013	$\frac{(100-700\ \boldsymbol{TYCOM\ mandays} + 560\ \boldsymbol{mandays}) * 0.95}{964\ (\frac{mds}{week})*4.33(\frac{weeks}{month})}$ $+7\ \boldsymbol{week\ end\ game}\ (\boldsymbol{includes\ DMD})$	5.8 months baseline

Figure 29. Evolution of Equations Used to Calculate Notional Duration per TFP

Despite the fact that the Rev A and Rev B of the current TFP are dated 2010 and 2012, respectively, a look at the FRE for DSRAs collected indicates that Rev A notional values were not implemented until early 2012 and Rev B notional values were not implemented until late 2013. By plugging in the final QAC data into the applicable equations, we can see that the notional durations per these equations and the actual planned durations do not match (Figure 30).

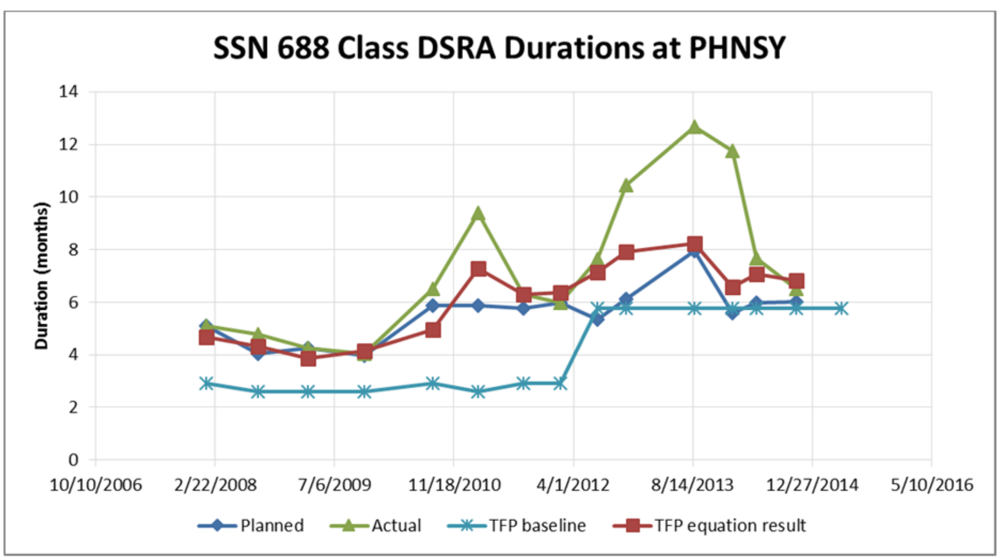

Figure 30. DSRA Duration Comparison with TFP Equation Result

When applying the final QAC data to the applicable TFP equation we see a higher notional duration than planned. This is likely a result of QAC re-baselining. This suggests that the QAC used is not the original QAC as provided by the FRE. Inputting the final QAC data into the TFP equation essential gives the duration result if the planners had been given perfect information. As shown in red on Figure 30, the TFP equation given perfect information does not adequately provide duration estimates in line with the actual durations of the DSRAs as shown in green on Figure 30. Notably, the actual durations do not begin to diverge from the TFP result by more than a month until mid-2012, which directly follows the shift to the 72 month OPINTERVAL. This divergence indicates that something has changed affecting the estimation equations ability to provide accurate estimates.

VI. CONCLUSION

A. FINDINGS

This investigation into the factors affecting SSN 688 class submarine maintenance delays at PHNSY highlights the difficulty in isolating one or two main factors. Data collection, maintenance, and dissemination at PHNSY was bureaucratic in nature. There does not exist a combined comprehensive data collection effort available to all the organizations involved in submarine maintenance. Each organization only maintains the data variables pertinent to that particular organization's reporting requirements and the lack of response to requests for data indicates a reluctance to give those data variables to outside organizations.

The data collection effort suggests that a major issue resides with an increasing average man-days/job in intermediate level availabilities (see Figure 21). At the intermediate level, maintenance facilities are completing fewer jobs per availability despite an increasing average duration per availability. This fact combined with the increasing number of deferred and cancelled jobs per availability indicates either a less experienced workforce or a lack of available intermediate level funding. The available data set for intermediate level availabilities does not contain sufficient workforce experience or funding data to prove or disprove the cause of this assertion. Additionally, the increasing average age of the submarines alone does not show a statistically significant relationship to the increased number of late days observed.

At the depot level, PHNSY is seeing a four-fold increase in late days despite only moderate decreases in cost performance. While the available data set does not contain sufficient variables to highlight the exact source of the increase in late days, what we can say is that this spike in late days corresponds with the implementation of the change from a 48-month OPINTERVAL to a 72-month OPINTERVAL in 2012.

An effort to determine the basis by which maintenance availabilities define their baseline durations yielded an in-depth analysis of the SSN 688 class DSRA TFP. This analysis reveals how TFP-based calculations may be systematically underestimating the

increase in the notional duration required for the 48 to 72 month OPINTERVAL shift. Specifically, many of the estimates used in the current duration calculation are still based on outdated historical averages of DSRAs conducted under the pre-2012 48-month OPINTEVAL.

B. FUTURE STUDIES

Future studies should continue to narrow the scope of analysis using the direction provided by this thesis. Specifically, future studies should attempt to answer the following questions:

- What is causing the increase in man-days/job observed in I-Level availabilities?
- Is the same job increasing in complexity over time or have workers become less efficient at completing the job over time?
- If workers have become less efficient over time, is this due to a decrease in workforce experience or due to a decrease in available resources (funding, or equipment)?
- Are we seeing a higher percentage of new work or is new work having a bigger effect? (confirmation of this thesis's assumption)
- If we are seeing a higher percentage of new work, is there a corresponding decrease in component reliability?
- Is there a statistically significant relationship between a higher percentage of new work and OPINTERVAL? If so, what should an updated TFP use for its new work percentage estimate?

Future studies will require a multi-person labor effort to bring data at the individual availability report level to a self-generated database level for analysis. Future analysis must obtain necessary data likely maintained by the shipyard and SUBMEPP. In addition to standard duration, cost, and performance data, future studies should attempt to

collect data regarding component reliability, workforce experience, and intermediate and depot level funding.

1. Component Reliability

Despite repeated attempts, this analysis failed to obtain component reliability data that may help remove component reliability from the list of possible factors affecting increased delays. If we assume that more failures are occurring during availabilities and are causing new work that extends the overall duration, then component reliability data is necessary to prove that the increased failures are not a result of less reliable components. A constant average time between failures would prove this hypothesis. The OPINTERVAL increase would represent an increased time between maintenance and therefore may explain the increased component failures seen in each availability despite constant component reliability rates. Component reliability data should be held by SUBMEPP because it reviews this data in order to optimize maintenance practices. However, efforts to obtain this data were unsuccessful for this study.

2. Workforce Experience

PHNSY & IMF workforce experience levels could also be driving the fact that increased new work is causing availability delays. A less experienced workforce could have two effects contributing to increased delays. First, a less experienced workforce would be less efficient thus directly increasing man-days necessary per job. Second, a less experienced workforce could produce less effective maintenance results thus leading to an increase in maintenance issues during each availability. Ideally, the increased work caused by ineffective maintenance should be categorized as work growth and charged to shipyard performance metrics; however, linking new work to past maintenance is extremely difficult.

3. I & D Level Funding

Future studies should use direct budgeting data to confirm if D-level priority of combined PHNSY and IMF resources is causing the decrease in I-Level maintenance production. Changes to an Engineered Operating Cycle (EOC) type maintenance strategy

requires a comprehensive study of all levels of maintenance, and therefore the interaction between intermediate and depot level maintenance cannot be overlooked. The increase in deferred and cancelled jobs per I-Level availability indicates that there may be inadequate available resources for intermediate level maintenance. The overall decrease in completed jobs per I-Level availability may be consequentially affecting D-Level availabilities as manifested by the increase in late days observed. Because PHNSY & IMF is a combined maintenance facility, maintenance across the yard is provided from over-lapping pools of resources. An example report of shared D-Level and I-Level resources at a combined maintenance facility is shown in Figure 31.

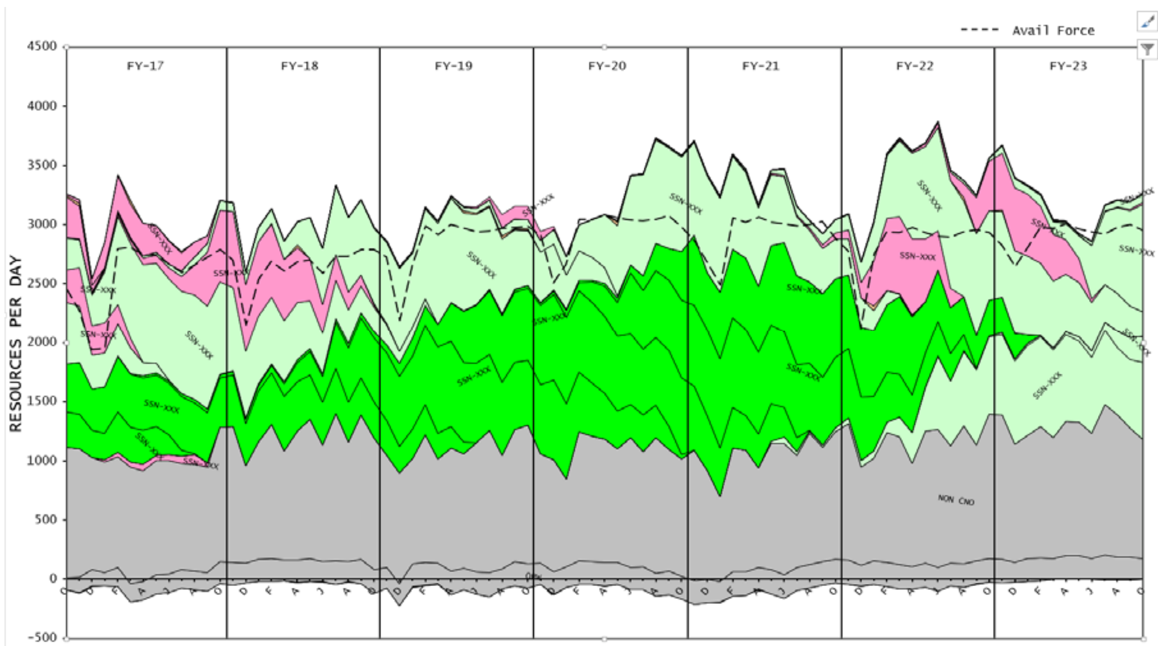

Figure 31. Typical "Layercake" Graph of Combined Maintenance Facility Capacity Usage. Adapted from sample WF-220 Report FY17–23.

The dotted line depicting 100 percent capacity level of the shipyard shows how the combined maintenance facility normally operates over-capacity. Therefore, D-Level and I-Level maintenance often compete for resources. Future studies should compare shipyard budget and demand resource levels at both I & D levels of maintenance to see if increased resource shortages correlate with poor availability performances.

C. RECOMMENDATIONS

1. Invest in Data Collection

Current data management practices of past submarine availabilities are inadequate to provide meaningful root cause analysis of identified issues. Ideally, all maintenance should be categorized and tracked under the categories provided by the TFP: baseline work, fleet alts, condition based/corrective actions per maintenance plan, deferred requirements, accelerated requirements, or new work. These types of maintenance should be separately tracked at the 000, 100–700, 800, and 900 Series SWLIN levels. Honest reason codes for deferred and cancelled work should be tracked to help future studies conduct root cause analyses. Additionally, all updates to estimated levels via a re-baseline should be done to each maintenance category at the SWLIN series level. Currently, planners use these maintenance type categories in their FRE but once an availability starts, the categories are largely discarded for conglomerated SWLIN level QAC, BQWP, and AQWP numbers. The separate maintenance categories previously mentioned are not further tracked or preserved and therefore a true comparison of work-planned vs work-completed at completion is not possible.

Additionally, the way in which new estimates are apportioned during the re-baseline process significantly hinders statistical analysis of past availability data. The re-baselines become mandatory when certain duration and monetary deviation thresholds are exceeded. Re-baselining is used primarily as an administrative tool to inform various higher-level stakeholders of the change to the availability. However, during the re-baseline process, all of the top line budget data is updated to best estimates at the SWLIN level. This typically results in an increase to both the "AWP MDS" and the "NEW WORK MDS" (from actual DSRA completion message). While administrative in intent, PHNSY uses these increased man-day budgets as their new budget baseline or QAC. Theoretically, re-baselining should only result from an increase in new work or due to poor performance but an empirical analysis of past DSRA completion messages shows that "AWP MDS" and "NEW WORK MDS" are typically increased proportionately. To compound the difficulty in analyzing historical data, the databases observed simply overwrite the old QAC with the updated re-baseline QAC. In order to compare planned

versus actual man-days, future studies will have to pull the original QAC numbers from the original FRE message for each availability individually.

2. Completely revamp the current TFP estimates and equations to accurately reflect the 72-month OPINTERVAL change

Recommend TYCOM implement a new revision to TFP, which discards the old estimates and uses all available data for best regression equations. First, there clearly needs to be an increased allotment for condition based/corrective maintenance and new work based on the increased time between depot level maintenance. The current TFP Rev B explicitly states that the Corporate Planning Estimates (CPE) for Condition Based/Corrective Maintenance "will be re-addressed as more DSRAs are accomplished on submarines after completing a 72 month OpInterval" (TFP rev B) yet there has not been any update since its release in 2012. Additionally, the notional new work budget of 20 percent non-nuclear services similarly fails to account for the effect of an increased OPINTERVAL. Because the total duration calculation used is a direct function of combined non-nuclear man-days, these updates will probably increase the notional duration to match more closely the increased durations observed. However, simply updating the corrective maintenance and new work budgets alone will not provide an accurate duration estimate. This can be seen by the difference between the actual duration observed and the TFP equation result shown by the green and red lines on Figure 30.

In order to fix the TFP duration equation, we propose using a two variable equation to replace the old single variable equation. The current TFP duration equation uses the total non-nuclear work as the only variable to the equation. As discussed in Chapter II.B.1, the equation attempts to estimate the duration by dividing the total non-nuclear work by a calculated "burn rate." This method does not take into account the fact that new work and non-new work (or planned work) inherently experience different burn rates. This is because new work is more likely to affect the critical path and therefore extend the total duration of the availability. When new work occurs it usually 1) must be done before another planned work can start or 2) is occurring after all the other production work is complete (during the retesting period at the end of the availability). This effect is illustrated in Figures 32 and 33..

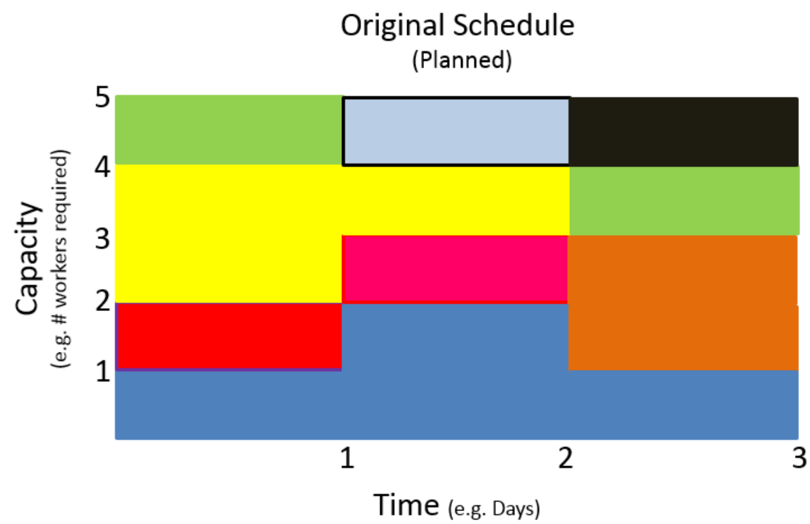

Figure 32. Simplified Maintenance Availability without New Work

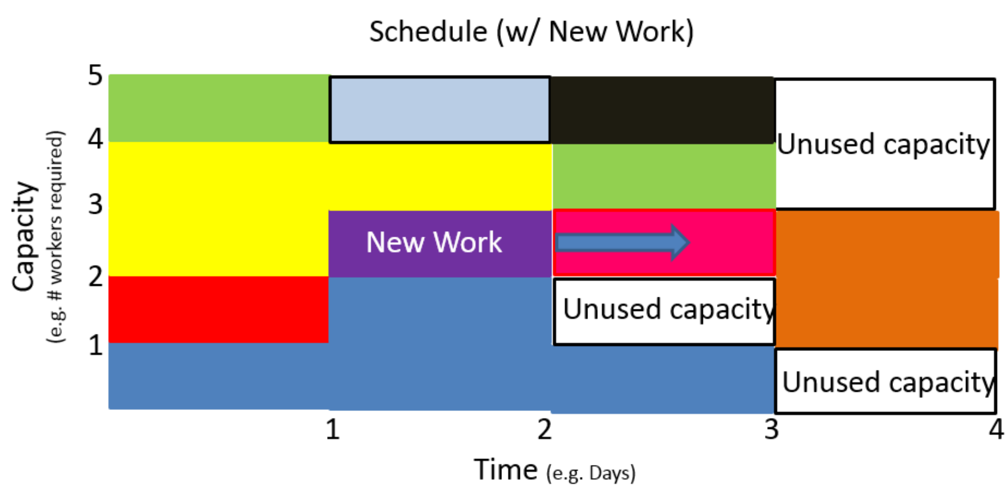

Figure 33. Simplified Maintenance Availability with New Work

In the example provided by Figures 32 and 33, an unexpected part failure has caused one man-day of new work, indicated in purple. This purple new work must be completed prior to starting the job indicated by the pink block, which is a prerequisite for the 2 man-day job indicated by the orange block. As you can see the one man-day of new work increases the total duration of the availability from 3 days to 4 days. Without accounting for new work the notional burn rate or max capacity observed in Figure 32 is 5 man-days per day (15 total man-days / 3 days). When one man-day of new work is added, the effective burn rate drops to 4 man-days per day (16 total man-days / 4 days)

wasting 4 man-days of capacity. This unused capacity observable by the white blocks in Figure 33 are not filled in with deferred or cancelled maintenance because the shipyard is operating under-capacity meaning those man-days have already been allotted for another boat. This decrease in effective burn rate observed by the increase in one man-day of new work can be extrapolated to show how an increase in the overall percentage of new work will decrease the effective burn rate. For this reason, in order to find an equation that uses as much historical data as possible, we propose using a separate average burn rate for planned work than for new work as shown in Figure 34.

Old Equation

$$\frac{(100-700\ TYCOM\ mandays\ +\ 560\ mandays)\ *\ 0.95}{964\left(\frac{mds}{week}\right) * 4.33\left(\frac{weeks}{month}\right)} + 7\ week\ end\ game\ (includes\ DMD) = \text{Old Total Duration Estimate (months)}$$

Proposed Equation

$$\frac{\text{Planned Work}\ mandays}{PWbr\ \frac{mandays}{month}} + \frac{\text{New Work Estimate}\ mandays}{NWbr\ \frac{mandays}{month}} + \text{fixed}\ mandays = \text{New Total Duration Estimate }(months)$$

Figure 34. Proposed Duration Equation Comparison

Regression analysis using data from all shipyards should be used to find the average planned work burn rate as labeled “PWbr” and new work burn rate as labeled “NWbr” in Figure 34. This thesis does not attempt to provide these variable coefficients because this thesis only collected data from PHNSY and because accurate new work data would be required. Once the variable coefficients “PWbr” and “Nwbr” and the y-intercept “fixed” are calculated the amount of new work expected using the current 72-month OPINTERVAL should be calculated from historical averages of only DSRAs conducted under the 72-month OPINTERVAL. Under the 48-month OPINTERAL, non-nuclear new work was calculated to be 20 percent of the non-nuclear planned work. Once an updated percentage of new work is obtained, the equation can be re-simplified down to a single variable equation if desired. If this simplification is down however, it will

become invalid if there is an expected change to the amount of new work such as what occurred during the OPINTERVAL shift.

The accurate estimation of man-days and duration required for maintenance is critical because the shipyard is manned and budgeted to those future estimates of demand. As shown in Figure 31, the shipyard is only manned and budgeted to around 70 to 80 percent of expected demand. The 80 percent limit for overall manning was originally proposed by Navy Sea Systems Support Group because in their own study they found that “historically, 20 percent of tasks were delayed due to work stoppages” (Nawara, 2013, p.11). If shipyards are systematically underestimating the man-days and durations required for these availabilities, then the shipyards are also systematically underfunding themselves below this 80 percent limit. This systematic underfunding can also serve as the root cause to any of the proposed possible causes to the negative performance trends such as decreased workforce experience or lack of available resources.

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LIST OF REFERENCES

Berger, J. O., & Sellke, T. (1987). Testing a point null hypothesis: The Irreconcilability of P values and evidence. *Journal of the American Statistical Association*, *82*(397), 112–122. Retrieved from http://socsci2.ucsd.edu/~aronatas/project/academic/Testing%20the%20Null%20Hypothesis.pdf

Caprio, J. L., & Leszczynski, D. (2012). *A preliminary investigation into CNO availability schedule overruns* (Massachusetts Institute of Technology Master's thesis). Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/7315/12Jun_Caprio_Leszczynski.pdf?sequence=1

COMNAVSEASYSCOM (2010, December 27). Technical foundation for the USS Los Angeles class docking selected restricted availability TYCOM Notionals [Letter 4700 Ser SEA 07/1332 to CNO]. Provided electronically by SUBPAC N4.

COMSUBPAC (2015). Naval Shipyard External Performance Review [Draft Letter 4790 Ser 00 to COMNAVSEA]. Unpublished draft letter.

COMUSFLTFORCOM/COMPACFLTINST N7. (2014, December 8). *Optimized fleet response plan* (COMUSFLTFORCOM/COMPACFLTINST 3000.15A). Washington, DC: CNO

Eckstein, M. (2016, March 29). Navy sub build strategy: Electric boat will focus on Ohio replacement while Newport News delivers more SSNs. Retrieved from https://news.usni.org/2016/03/28/sub-build-strategy-electric-boat-will-focus-on-ohio-replacement-while-newport-news-delivers-more-ssns

Kalowsky, J. (n.d.). *Analysis of SSN 688 class submarine dry docking selected restricted availabilities (DSRA)* (Tech.). Norfolk, VA: NAVSEA Norfolk Naval Shipyard.

Kim, H. (2016, November). Congressional process 101. Lecture presented at Conrad Seminar in Naval Postgraduate School, Monterey, CA.

Luther, B. (2016, November). Budget officer overview fiscal update. Lecture presented at Conrad Seminar in Naval Postgraduate School, Monterey.

NAVSHIPYD AND IMF PEARL HARBOR HI. (2014, October 1). *USS Cheyenne (SSN 773) DSRA 2 completion*. Pearl Harbor, HI: COMNAVSEASYSCOM WASHINGTON DC

Nawara, T. M. (2013). *Resource constrained scheduling problem at U.S. Naval Shipyards* (Master's thesis). Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/40243/13Jun_NARAWA_CIVINS.pdf?sequence=1

OPNAV N9. (2013, January 22). *Submarine engineered operating cycle program* (OPNAVINST 3120.33C). Washington, DC: CNO.

OPNAV N431. (2010, May 25). Maintenance policy for United States ships (OPNAVINST 4700.7L). Washington, DC: CNO.

PHNSY & COMSUBPAC. (2015). Naval shipyard external performance review [excel data files]. Unpublished data. Retrieved from PHNSY N4 Office.

SUBMEPP. (2012, August 17). *Technical Foundation for SSN 688 Class DSTA TYCOM Notionals Revision B* (Tech.). Portsmouth, NH: Portsmouth Naval Shipyard.

SUBPAC N4. (2016, March 30). Submarine Maintenance Analysis Needs. Presented at RO/MO Conference in Naval Postgraduate School, Monterey, CA.

SUBPAC N4. (2017, January 23). [DA Report Data]. Unpublished raw data.

SUBPAC N4. (2017, February 27). Submarine Maintenance Analysis. Presented at RO/MO Conference in Naval Postgraduate School, Monterey, CA.

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